MINUTES OF PROCEEDINGS

OF

THE INSTITUTION

OF

CIVIL ENGINEERS;

WITH OTHER

SELECTED AND ABSTRACTED PAPERS.

VOL. XCII.

EDITED BY

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CORRIGENDA.

Vol. lxxix., p. 127.	The total of the column, "Cost per train-mile" for 1883, should be 39·89*d.*, instead of 59·89*d.*
,, xci., p. 447.	Last line, *for* "9th of September" *read* "7th of September."
,, ,, p. 518.	The Author of the Paper, "The connection between the heading-up due to Weirs, etc.," is Mr. J. Latif Bey Manoug. M. Inst. C.E., and not Mr. Kindermann. The latter prepared it for publication.
,, xcii.	Plate 3, Figs. 12 and 14, *for* "Kippregle" *read* "Kippregel."

THE

INSTITUTION

OF

CIVIL ENGINEERS.

SESSION 1887-88.—PART II.

Sect. I.—MINUTES OF PROCEEDINGS.

10 January, 1888.

GEORGE BARCLAY BRUCE, President,
in the Chair.

The following Associate Members have been transferred to the class of

Members.

Thomas Philip Sherard Crosthwait, B.A. | Frank Alexander Brown Geneste.

The following Candidates have been admitted as

Students.

Robert Adam.
William de Lacy Ahern.
Herbert Edward Allen.
Frederick Robert Bader.
James Benjamin Ball.
Ernest Vivian Bowman.
Richard Alexander Chattock.
Edward James Duff, Wh.Sc.
Arthur Frederic Ennis.
Herbert Taynton Foord.
Charles Chetwode Hardy.
Philip Eliot Hodgkin.
George Hutcheson McCowat.
James Peter McMillan.
Percy Walter Maddock.
Kenneth MacLewin Monteath.
Eugene Joseph Moynihan.
Arthur Boyd Price.
Thomas Rogers.
Najeeb Mansoor Shakoor.
Elias Demetrius Simitopoulos.
John Tourtel.
Wilfrid Lawson Spence.
Edward Hyde Robert Wybrants Wade.
Ernest Moore Wilson.
Frederick James Wright.
Charles Henry Yeaman.

The following Candidates were balloted for and duly elected as

Members.

Alfred Morcom. | John Richard Schram.

Associate Members.

Henry Fitzgerald Beale.
Alexander Bewicke Blackburn.
Arthur George Brown.
Evelyn George Carey.
William Thomas Curry.
George James Findlay.

Associate Members—continued.

FRANCIS SEBASTIAN BURKE GAFFNEY.
ARTHUR HARLEY.
GEORGE WILLIAM HIGHAM, Stud. Inst. C.E.
WILLIAM PREST HOUSDEN.
HERBERT KINGSFORD.
MASA KUWABARA, M.E.
FRANK BECKET LEWIS.
WILLIAM JOHN MCKENZIE.
The Hon. EDWARD HERBERT SCOTT NAPIER, Stud. Inst. C.E.
PETER NORDENFELT.
HERBERT JOSIAH PARSONS.
EMANUEL JOSEPH RISTORI.
GEORGE PRINGLE ROSE.
ROBERT JULIAN SCOTT.
EDWARD SYKES.
GEORGE HERBERT WAILES, Stud. Inst. C.E.
KAICHI WATANABE, B.Sc.
ARTHUR HENRY WHYTE-BUTLER.
WILLIAM WILLOX, M.A.
MAURICE WILSON, Stud. Inst. C.E.
JEREMIAH WOLSTENHOLME.

(*Paper No. 2223.*)

"The Use and Testing of Open-hearth Steel for Boiler-making."

By the late HAMILTON GOODALL, Assoc. M. Inst. C.E.

WHEN the Author first began to use open-hearth steel, in 1875, for boiler-making, he found he had to deal with a material differing in many respects from any of which he had previous experience, and presenting certain peculiarities difficult of explanation.

At that time rivet-holes in shell-plates were punched, and it was noticed that sometimes the punch passed through a steel plate as though it were lead, while with other holes in the same plate the operation was attended with a sound like the report of a pistol. Evidently the material was not homogeneous, and experiments showed the variations to be greater than expected. It was only when heated that the plates gave any difficulty, some plates failing in flanging and thinning, which stood all tests required by the British Admiralty, the Board of Trade, and Lloyd's Registry. Probably the cause of this might have been discovered by an elaborate chemical analysis, coupled with the experience of a steel-manufacturer's chemist; but as these unfortunately are not sufficiently at the command of a boiler-shop manager to enable him to depend upon them in everyday working, the Author tried to discover some simple mechanical test which would supplement those made at steel works under different rules.

If a plate cracks in working, the tensile-test piece, 8 inches or 10 inches long, is of no use in determining the nature of the material near the crack; the test must be more localized, and the Author thought that some information might be obtained from a drifting-test, such as was referred to by Mr. Daniel Adamson at the Paris meeting of the Iron and Steel Institute in 1878, where the washers had a hole drilled through them, equal in diameter to

a rivet-hole as used for the same thickness of plate, and an outside diameter equal to the lap of such a plate, with a single-riveted joint.[1]

The Author tried some tests in this manner with washers $2\frac{3}{4}$ inches in diameter, having $\frac{15}{16}$-inch holes. They were drifted out under a 5-cwt. steam-hammer by as gentle blows as could be given, using drifts 5 inches long, having a taper of $\frac{3}{8}$ inch in their whole length. Washers taken from furnace-plates were drifted out to an average of 2·73 inches in diameter of hole, from shell-plates of 2·59 inches; but the results showed some discrepancy, probably due, in the absence of special machinery, to the use of a steam-hammer, although every care was taken.

It is often necessary to test plates which appear to have suffered, or which for other reasons it may be desirable to examine; but for doing so these tests were as bad as a tensile-test, since the plate was spoilt by cutting the pieces out, and if the result proved the plate to be sound, it could not be further used. To meet this difficulty the Author decided to obtain washers from the material usually taken out of plates for rivet-holes, and he therefore arranged a series of tests such as might be cut from a $\frac{7}{8}$-inch rivet-hole, the smallest used for ordinary marine work. For purposes of comparison, these washers were made one-quarter the size of washers previously tested, their outside diameter being $\frac{11}{16}$ inch, with a drilled hole $\frac{15}{64}$ inch.

A special machine was made, in which the drifts, well oiled, were advanced at a uniform rate of 1 foot per minute, so that no variation could occur in the conditions of each test. The washers were drilled out at right-angles to the surface of a $\frac{13}{16}$-inch shell-plate, some being afterwards parted in a lathe into two and three equal parts. The drifts had a taper of $\frac{1}{4}$ inch in 5 inches; the first was $1\frac{1}{4}$ inch long, and tapered from $\frac{1}{4}$ inch to $\frac{3}{16}$ inch, the next two were $1\frac{7}{8}$ inch long, and all others $2\frac{1}{2}$ inches, the diameter of hole in the bolsters being $\frac{1}{32}$ inch larger than the drifts used with them. Results of the tests are given in Table I, and show an average drifting-diameter of 0·645 inch for full thickness washers, unannealed and annealed, for one-half thickness, 0·59 inch unannealed, and 0·554 inch annealed, and for one-third thickness, 0·535 inch unannealed, and 0·555 inch annealed.

Washers were also cut out lengthways and crosswise of the plate, that is, with axes parallel to the surface of the plate. They were tested $\frac{13}{16}$ inch, $\frac{1}{2}$ inch, and $\frac{3}{8}$ inch thick, and the results, some of which are given in Table II, show an extraordinary reduction

[1] The Journal of the Iron and Steel Institute, 1878, p. 383.

in drifting-diameter, as compared with Table I. The average results were, that the plate $\frac{13}{16}$ inch thick, lengthways, unannealed, drifted to 0·457 inch; $\frac{1}{2}$ inch thick, lengthways, to 0·432 inch unannealed, and 0·489 inch annealed, crosswise to 0·5 inch and 0·494 inch; $\frac{3}{8}$-inch thick, lengthways to 0·468 inch unannealed, and to 0·442 inch annealed, crosswise to 0·432 and 0·447 inch.

All these washers broke at parts originally near the centre of the plate; and this, with tests of washers cut into two and three parts (Table I), seems to show how rolling strengthens the skin of the plate. The Author thinks these results may probably be of use in ascertaining the proportion between the thickness of the ingot and of the plate into which it is rolled.

Tests were then made to ascertain the load on the drift necessary to break the washers. The results showed a variation from 68 to 71 cwt., the mean being $70\frac{1}{6}$ cwt. for those drilled at right-angles to the surface of the plate, and from 50 cwt. to 53 cwt., the mean being $51\frac{2}{3}$ cwt., for washers of the same thickness ($\frac{13}{16}$ inch) cut out lengthways, all being unannealed.

The difficulty of accurately ascertaining the friction in drifting prevented reliable comparison between the tensile-strength of these washers with that of ordinary test-pieces; but failing this, the Author endeavoured to establish some relation between the elongation of a washer and the elongation in a length of 8 inches of plate. It is evident that in drifting a washer; the inside is in compression and the outside in tension; efforts were therefore first made to find the neutral circle. In a washer $2\frac{3}{4}$ inches in diameter, $\frac{13}{16}$ inch thick, the hole being $\frac{5}{16}$ inch in diameter, a circle 2 inches in diameter was, after drifting, $2\frac{23}{32}$ inches, and exactly midway between the outside and the inner edge; the hole drifted to $2\frac{1}{4}$ inches, and the outside diameter to $3\frac{9}{16}$ inches, the extension being 45·3 per cent.

An 8-inch test-piece, of the same section as this washer, showed a tensile-strength of 27·5 tons per square inch, an average shearing-strain of 20·23 tons, and an elongation of 27·34 per cent., so that the radial distances, before drifting, outside the 2-inch circle ($\frac{3}{8}$ inch) and inside it to the edge of the hole ($\frac{17}{32}$ inch), are very nearly in inverse proportion to the tensile- and the shearing-strains.

In a further test, a washer, and a piece from the same plate $6\frac{9}{32}$ inches long, equal to the circumference of the 2-inch neutral circle, and of the same section as the washer, were prepared and each marked off into six equal divisions. The elongation per cent. per division was as follows:—2-inch circle first and second divi-

sions 37·3, third division 57·62, fourth 76·6, and last two divisions 40·3; test-piece, 20·36, 28·96, 28·0, 71·94, 22·27 and 18·45; mean of the former 48·2, of the latter 31·66.

With eight washers of the same size, the drifting-tests showed an average diameter of hole of 2·3 inches, and an average extension on the 2-inch neutral circle of 46·95 per cent. The Author thinks that these may be taken as a standard of comparison, that is, that the hole of a large washer drifting out to 2·3 inches in diameter, and that of a small one to 0·645 inch, would fairly represent an extension of 27 per cent. in 8 inches.

In Tables I and II (pp. 24, 25) is placed a column giving the variation of elongation, equivalent to an elongation in 8 inches, per cent., worked out in this way, taking 60 per cent. as the normal elongation on the neutral circle.

The annexed Tables, giving a record of average drifting-diameters, the elongation in 8 inches of the pieces tested, the calcu-

Number of Test.	Average Drifting Diameter.	Actual Elongation in 8 inches.	Calculated Elongation in 8 inches.	Average Drifting Diameter.	Actual Elongation on Neutral Circle.	Calculated Equivalent Elongation in 8 inches.
	Inch.	Per cent.	Per cent.	Inch.	Per cent.	Per cent.
217	0·645	27·34	27·00	0·281	1·56	0·70
227	0·510	11·72	16·41	0·312	6·25	2·84
228	0·604	25·00	23·44	0·343	9·38	4·22
229	0·479	17·97	13·60	0·375	12·50	5·63
231	0·500	10·16	15·47	0·406	18·75	8·44
232	0·489	12·50	14·53	0·437	25·00	11·25
234	0·531	17·20	18·28	0·468	28·13	12·66
235	0·500	22·00	15·48	0·500	34·38	15·47
237	0·604	18·00	23·44	0·531	40·63	18·28
238	0·598	29·00	24·10	0·562	46·87	21·09
240	0·666	25·50	29·08	0·593	50·00	22·50
242	0·572	18·75	21·56	0·625	56·25	25·31
251	0·682	29·50	30·47	0·656	62·50	28·13
253	0·598	27·00	22·97	0·687	68·75	30·94
258	0·650	29·50	27·57	0·718	71·88	32·35
259	0·684	25·00	30·68	0·750	78·13	35·16
262	0·640	25·00	26·72	0·781	84·38	37·97
263	0·630	25·00	25·78	0·812	90·63	40·78
264	0·625	25·00	25·31	0·843	93·75	42·19
269	0·697	29·50	31·41	0·875	100·00	45·00
275	0·569	25·50	21·40			
285	0·651	24·50	26·66			
289	0·739	29·70	34·22			
Average . .		23·08	23·76			

lated elongation as deduced from the washers, the actual elongation on the neutral circle, and the calculated equivalent elongation in 8 inches have been compiled to check this method of deducing the

elongation in 8 inches, from that of the neutral circle of a washer. The results of the drifting-tests when compared this way are somewhat startling; but it will be seen that the difference between the actual and the calculated elongation is only equal to 0·054 inch in 8 inches, and as it is not unusual for the elongation of two tensile-test pieces from the same plate to vary as much as 5 per cent. in 8 inches, a closer agreement cannot be expected with different plates.

To obtain further information as to the variations in the same plate, some tensile-test pieces were prepared, having a section equal to that of a small washer. They were made 8 inches and $1\frac{9}{16}$ inch long, the latter being equal in length to the circumference of the neutral circle of the small washer. In Table III the mean results obtained from three tests are stated, together with the variations in breaking-strain, reduction of area, and elongation; the mean and variation of six shearing-tests, lengthways and crosswise, are also added; and if these be compared with similar particulars given in Tables I and II, for the drifting-tests, it will be seen that the latter show the greatest variation, indicating that this test is the most sensitive one.

All the washers and test-pieces of which particulars are supplied in Tables I to III were cut from one shell-plate; for the sake of comparison tests were made with washers taken from a series of furnace-plates of special quality, having an average tensile-strain of 26 tons per square inch. Eleven washers were cut from the flange of a back tube-plate $\frac{3}{4}$ inch thick, and six washers from each of eleven stiffening-rings of furnaces, $\frac{1}{2}$ inch thick, after flanging. The $\frac{3}{4}$-inch washers were drifted to a mean diameter of 0·684 inch, the mean of the $\frac{1}{2}$-inch washers varied from 0·593 to 0·687 inch, the average of the whole number being 0·644 inch, as compared with 0·645 inch for shell-plates; this then is taken as the normal diameter for a good plate. The greatest variation in the diameter of hole after drifting was from 0·531 to 0·75 inch, this being equivalent to an elongation in 8 inches of from 18 to 35 per cent.

The Author thinks the following conclusions may be drawn from these experiments:—

I. That the drifting-test is a very sensitive one, and, as it can be applied to a small area, it will give information not obtainable with other tests.

II. That allowing for variations in material, it may afford valuable information as to the behaviour and treatment of steel plates in various stages of manufacture into boilers.

The investigations which the Author proposed to pursue, with the aid of this test, were those which he considered most likely to result in a solution of the difficulties experienced in using steel plates; they comprise the welds of furnaces, and the effects of hammering, of compression, of punching and shearing, of flanging, of annealing, and of heat, and tests of defective plates.

I. The Welds of Furnaces.

Nothing, perhaps, in a boiler-shop requires more carefully watching than the welds of furnaces. They may be bad and may show it unmistakably; but they may be overheated and may show no signs of it. In Table IV will be found particulars of tests taken from the flanged stiffening-rings of furnaces, three of them being good welds, giving an average size of hole of 0·447 inch, and two of them being second rate and only giving an average diameter of 0·328 inch. It must be remembered that the plates were flanged after being welded, and the weld is thus very much strained. The Author thinks that if a flanged-weld drifts out to 0·406 inch it represents a fairly good weld; below this the plate is most likely burnt.

Test No. 284, Table IV, is taken from the weld in a stiffening-ring after being flanged, and not only shows that the weld is second-rate, but it shows also that the breaking-strain is reduced to about one-half of the original, with an elongation equivalent to about 3 per cent. in 8 inches; that is, that the diameter of hole after drifting is reduced from 0·625 inch to 0·312 inch, and the pressure on the drift necessary to burst the washer is reduced from 35 and 38 cwt. to 18 cwt. That a plate can be so spoilt and yet show no outward signs of the damage is a fact by no means consolatory to those upon whom the responsibility of detection falls.

II. The Effect of Hammering.

When steel plates first came into use it was customary to heat the ends of shell-plates which are not bent in the rolls in order to set them to the required curve for butt-straps or for lap-joints. It was found, however, that this local heating was in some cases injurious to the plates. The results of numerous tensile-tests, made by the Author on strips cut out of plates so heated, showed that the elongation was reduced in certain cases from 28 down to 12 and even 6 per cent. in 8 inches, whilst in

other cases no reduction was observed. It was therefore determined to set the ends up cold, and certain tests were made to see if the plates were damaged by doing so. A piece of plate was hammered to a radius of 6 feet for a distance of 12 inches from the edge.

A tensile-test piece from the solid plate showed a breaking-strain of 27·52 tons per square inch, with an elongation of 27·3 per cent. in 8 inches. The average of three tests out of the hammered part gave a breaking-strain of 28·22 tons per square inch, with an elongation of 27·4 per cent. It seemed, therefore, that no harm was done by cold hammering. The drifting-test was used to check the tensile-test.

Tests Nos. 224, 272, 277 and 285, of which details are given in Table V, were made with this purpose, and it will be seen that the effect of the cold hammering was to reduce the ductility of the material to an extent equivalent to an average loss of elongation in 8 inches of 7·89 per cent. where the plate was bent to a radius, and to 5·01 per cent. for those hammered flat unannealed; the average reduction of the annealed tests hammered flat was 7·74 per cent. The annealed tests Nos. 277 and 285 were made to see if this reduction of ductility would be restored by the process of annealing; the results in No. 277 show that whereas the average diameter of hole in the washers not annealed was reduced from 0·648 inch to 0·571 inch, that of the annealed washers was reduced from 0·656 inch to 0·531 inch. In No. 285 the corresponding figures were, not annealed, 0·651 inch reduced to 0·589 inch; annealed 0·696 inch reduced to 0·625 inch.

In test No. 285, the only one of this series in which the greatest load on the drift was registered, the average bursting-pressure on the drifts was as follows:—

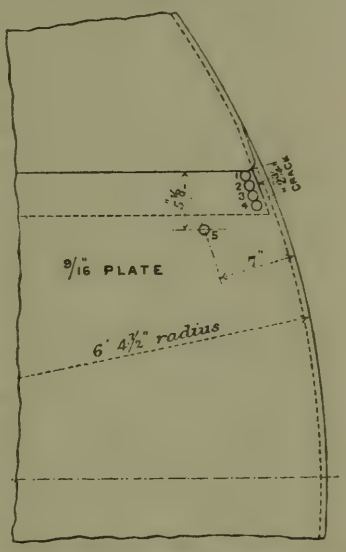
Not Annealed.—Average bursting-pressure $51\frac{5}{7}$ cwt. on the part not hammered, reduced to $50\frac{7}{8}$ cwt. on the hammered part, being a reduction of 1·62 per cent.

Annealed.—Average of $48\frac{3}{7}$ cwt. reduced to 47 cwt.; reduction 3·13 per cent.

As these tests showed a considerable reduction of ductility and of tensile-strength due to cold hammering, it was thought better to abolish the practice where practicable, and the plates for the shells of boilers are now usually ordered longer than required, that part not bent in the rolls being cut off after the plates have been bent. There is thus no strain put upon the plate, except the gradual bending in the rolls, which, as numerous tests have shown, does not produce any ill effect.

There is another peculiarity in the behaviour of steel when hammered cold; this is illustrated by the number of plates in the ends of boilers which have cracked in the corners while being closed by the riveting-hammers. Test No. 207 (Fig. 1) was a case of this kind. In four washers, Nos. 2 to 5, from the cracked corner the drifting variation was from 0·468 inch in No. 2 to 0·812 inch in No. 5, equivalent to a difference of elongation in 8 inches of from 13 to 41 per cent. Washers from the other corner which did not crack varied from 0·468 to 0·75 inch, the mean of ten washers being 0·615 inch; from the solid plate the variation was from 0·531 to 0·687 inch, the means of three washers all annealed being 0·614 inch. So far as the Author's experiments enable him to judge, he does not think that any amount of hammering put upon a plate in ordinary working could deteriorate it to this extent; the plate was evidently of poor and unequal quality, and he attributes this failure to the strain put upon the plate in the heating, hammering, and fitting, by the irregularities in its composition, and under the riveting-hammers this strain readily developed into a fracture. Other peculiarities exist in the behaviour of steel when hammered, but as they are noticed when the hammering acts in conjunction with heat, they will be treated of under the head of heat and defective plates.

FIG. 1.



In spite of the great general superiority of steel over iron, it is distinctly inferior to it in its ability to resist the two forces of heat and hammering. The Author does not think that this weakness is owing to any inherent defect in the material; but that it is due to the mode of manufacture. Were steel homogeneous, the difficulties which hamper the use of it would disappear; but so long as the variations continue, which have occurred in every steel plate that the Author has tested, so long will there be defective plates, failing often, most provokingly, in the last stage of manufacture into boilers, and entailing great expense and loss of time upon the boiler-makers.

III. The Effect of Compression.

The failures which sometimes happen, in which the plate seems to give way under compression, led the Author to make some experiments in this direction. The following tests only show the effect of compression; as under the head of "Flanging" will be given the effect of compression accompanied by heat and work.

The most severe form of compression to which a plate is subjected, is probably that on the burr, which is made when punching a hole. Drifting-tests were taken out of six burrs unannealed, and six annealed (Table V). The size of the burrs was $1\frac{1}{16}$ inch in diameter at the top, and $1\frac{1}{4}$ inch in diameter at the bottom; so that the washers which were $\frac{11}{16}$ inch in diameter were unaffected by the damage done to the outside of the burr in punching. The compression was so severe that these burrs, punched out of a $\frac{13}{16}$-inch plate, were reduced to $\frac{3}{4}$ inch thick. The washers unannealed drifted to an average diameter of hole of 0·645 inch, or the same size as the washers drilled out of the plate. The annealed tests show an average of 0·614 inch as compared with 0·645 inch out of the solid plate. As the compression on these burrs was undoubtedly very severe, but as the actual compressive-strain was not known, other tests were prepared from a plate squeezed up in a hydraulic riveter. The pressure on the plate was about 20 tons per square inch, and the plate was reduced in thickness from $\frac{13}{16}$ inch to $\frac{3}{4}$ inch and $\frac{25}{32}$ inch. The plate was the same as used for the burr-tests, and particulars are given in Table V; the washers, unannealed, drifting out to an average diameter of hole of 0·687 inch.

The conclusion arrived at was, that compression up to 20 tons per square inch does no harm; when, however, it is accompanied by heat and work, it is a source of weakness in a plate.

As the shearing-strength of the plate used for these tests is in proportion to the tensile-strength as 1·0 is to 1·36, it is evident that in bending a plate to a radius it is the inside which, being in compression, will fail first. This is frequently noticed in the tempered bending-test, and in other cases during the manufacture of boilers, where the plate in cracking starts from the inside.

IV. Punching and Shearing.

In flanging iron plates, such as the saddles of furnaces, it was found necessary to chip the edge of the plate where it had been punched or sheared, as, if left rough, the plates were very liable

to crack when stretched in flanging. It was found that steel behaved in the same way as iron, and a test was made to determine how deep the damage caused by punching and shearing went into the plate. The average size of hole after drifting was as follows, the distances given from the edge of the washer to the edge of the plate being measured on the top side of the plate :—

Not annealed.

	Inch.
Out of solid plate	0·677
Punched edge : the edge of washer $\frac{5}{32}$ inch from edge of plate	0·677
Sheared edge, ditto	0·651
Punched edge : the edge of washer $\frac{1}{32}$ inch from edge of plate	0·645
Sheared edge, ditto	0·687

These tests show that the damage does not extend more than $\frac{1}{32}$ inch from the edge of the plate, and this is all that it is found necessary to chip off.

It would be beyond the scope of the Paper to notice the numerous tests that have been made to ascertain the value of punched and of drilled holes. The result has been in favour of drilled holes; but the drilling-machines now made are so well adapted for their work, and the plates are so much larger and more difficult to handle than the smaller ones in use before the introduction of steel, that apart from the superiority of drilled over punched holes, the question may be said to have been settled from economic considerations. The Author has, therefore, only briefly referred to the effects of punching and shearing as still in use in a boiler-shop; that is, for cutting the edges of plates to the required form.

V. The Effect of Flanging, etc.

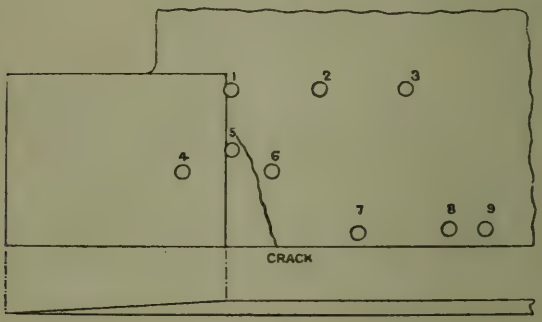
Much trouble is occasioned, in fitting the backs of boilers, by the outside plate cracking in the corner of the flange; an instance having been given under test No. 207, Fig. 1, it was resolved to make some tests in order to find out the cause. A test was made to see whether the size of the radius of a flange had any effect in weakening the plate. A $\frac{3}{4}$-inch plate was flanged at a right-angle to a 3-inch inside radius at one end, and at the other end was forged square, the plate gradually tapering with a constantly diminishing radius from one to the other. Washers were drilled out of the top of the radius, were turned parallel and were cut in two. The average drifting-diameters were as follow :—

				Inch.
Nos. 1 to 4,	out of large radius:	top half drifted to		0·656
„ 1 „ 4	„ „ „	bottom	„	0·601
„ 5 „ 8	„ small „	top	„	0·609
„ 5 „ 8	„ „ „	bottom	„	0·562
„ 1 „ 16,	out of solid plate:	top	„	0·625
„ 1 „ 16	„ „ „	bottom	„	0·644

These tests show that a large radius is preferable to a small one; and they also show how, even with a large radius, the inside of the plate suffers from the compressive-strain to which it is subjected.

In thinning the corners of shell-plates under the steam-hammer for lap-joints, it was found that steel plates occasionally cracked at right-angles to the long side of the plate. This crack usually took place where the blue heat came. Thus, in the early days of steel the rivet-holes were punched up to about 12 inches from the end

FIG. 2.



of the plate, and in thinning the corners the plate sometimes cracked from the hole to the edge of the plate. The holes were taken back to 2 feet from the end of the plate, but plates still occasionally cracked in the blue heat part.

Test No. 287, Table VI, gives a sample of this; the corner of a shell-plate was being thinned out under the steam-hammer, and cracked as shown in Fig. 2. Small washers drilled out, give a drifting variation of from 0·5 inch on one side of the crack to 0·625 inch on the other side and 0·687 inch elsewhere. The variation from 0·5 inch to 0·687 inch represents a difference of elongation in 8 inches of from 15 to 31 per cent. in the space of a few inches. The variation in the greatest load on the drift required to burst the washer was from 59 to 78 cwt., or 32 per cent. Here is shown the result of a combination of the three enemies of steel, heat, hammering and heterogeneity.

The result of this investigation was to abolish the practice of thinning the corners of shell-plates under the hammer, where practicable, in favour of scarfing them in a machine. Test No. 233, Table VI, was made to compare corners, thinned in these two ways; and they were thinned before being flanged. Washers were drilled out of the radius as well as out of the tapered part. Those out of the hammered tapered part show an average drifting-diameter of 0·656 inch; those from the scarfed tapered part 0·621 inch; but in the radius the sizes are 0·679 inch hammered, and 0·695 inch scarfed. The advantages of each method of working are thus pretty evenly balanced, with a good plate, and the hammering is only found objectionable with plates of inferior quality, no difficulty being experienced with plates of special quality for furnace work. Many other flanging-tests were made, which it is not necessary to describe; they showed the great suitability of steel plates of fairly good quality to withstand the strains put upon them in working. One test is interesting as giving a drifting-diameter of 0·875 inch, being the highest yet obtained. It was taken out of the radius part of a plate which had been flanged to a right-angle and then straightened.

When steel first came into use there was a good deal of trouble caused by the overheating of plates in flanging. Flangers were in the habit of heating steel plates to the same extent as they had been accustomed to heat iron, and many plates were spoilt in consequence. In every case of overheating, the edges of the plates were burnt away, and the damage was easily detected by the rounded corners. In order to determine how far they were damaged, a test, No. 278, Table VI, was prepared. A piece of ½-inch plate was flanged to a right-angle, one end being overheated so as to make the metal run; and washers were drilled out on the usual rivet-line. The effect of overheating was only perceptible in the end washer, which gave a drifting-diameter of 0·5 inch, the others averaging 0·677 inch. Another row of holes was drilled nearer to the edge of the plate, and though the washers showed signs of over-heating, yet they drifted out to an average of 0·644 inch.

VI. Annealing.

Annealing is very often considered to be a panacea for all the ills to which steel is liable; yet the practice of engineers varies very much. Some anneal all the plates that have been locally heated, and others only anneal plates when specified. The points

which the Author wishes to bring before the Institution are three in number:—

I. Is a steel plate damaged by local heating?

II. If damaged, is it restored wholly or partially to its original strength and ductility by annealing?

III. Have tests been made with a view to determine these points? or, if not, are any results published to show that a certain percentage of steel plates has failed; while, in the same establishment, on the same class of work, and with the same make and quality of steel, the percentage of failures with annealed plates has been less?

The practice of the best boiler-makers is undoubtedly to anneal plates, but the question is, what experiments and experience have led them to do so?

From numerous tensile-tests of plates unworked and locally heated, the Author finds that sometimes the breaking-strain is apparently increased by annealing, and sometimes diminished, the balance being in favour of those diminishing. The same irregularity exists with the elongation of the tensile-, and drifting-tests, the balance being in favour of those increasing; whilst in about 15 per cent. of the tests no alteration of ductility was noticed. The Author is now only speaking of plates that have been locally heated, and not of the very curious effect that annealing has in restoring the strength lost in punching.

It was not found necessary to anneal iron plates, and it is a question whether it be necessary to anneal steel plates, or at all events those with a high tenacity and a low percentage of carbon.

Test No. 290, Table VII, gives the results of tests taken out of the saddle-plate of a furnace. The breaking-strain of the original plate was 26·3 tons per square inch, and the elongation in 8 inches 25 per cent. The average drifting-diameter of the plate taken after bending and flanging, but out of a part unaffected by work or local heat, was 0·723 inch unannealed, and 0·703 inch annealed.

The average bursting-load on the drift was $41\frac{1}{6}$ cwt. unannealed and $40\frac{1}{2}$ cwt. annealed. The tests out of each of the flanged parts are given separately, but the average drifting-diameter was 0·65 inch unannealed and 0·644 inch annealed; the average bursting load $40\frac{11}{16}$ cwt. unannealed and $38\frac{13}{16}$ cwt. annealed. Tests were taken across the weld, that is, at right-angles to it, and gave an average drifting-diameter of 0·648 inch unannealed and of 0·632 inch annealed; the average bursting load was $44\frac{4}{13}$ cwt. unannealed and $41\frac{3}{13}$ cwt. annealed.

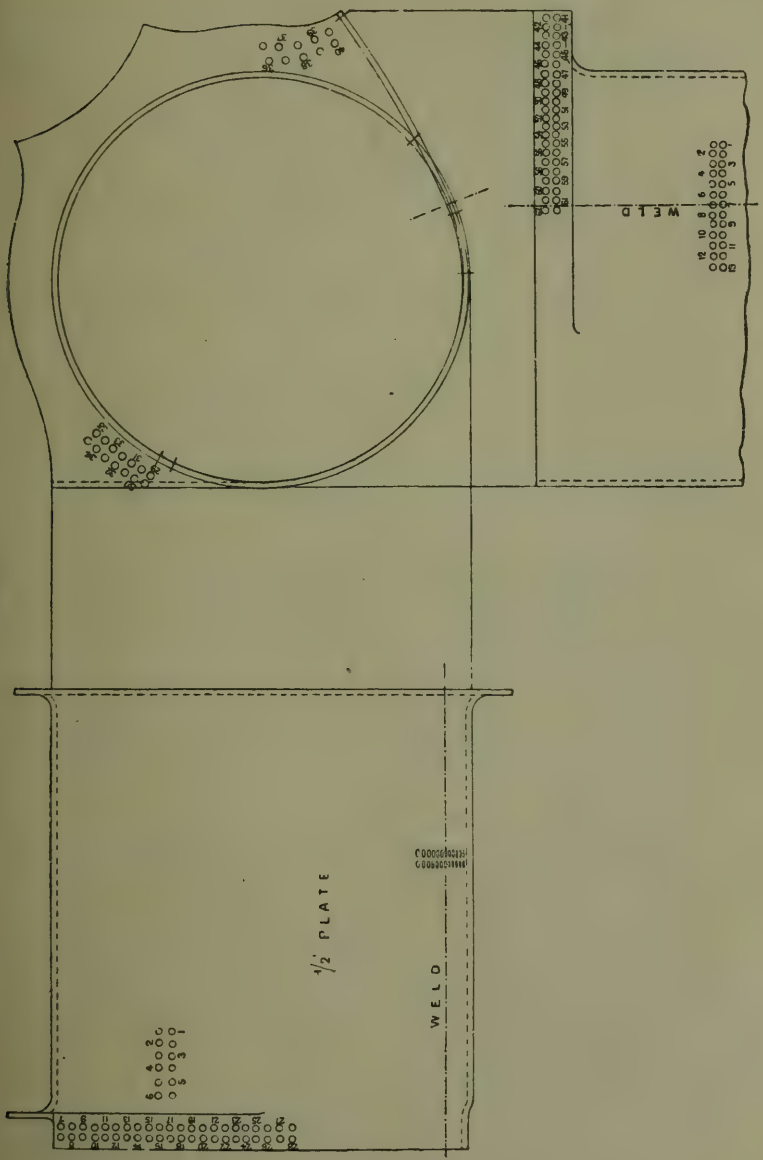


FIG. 3.

It will be noticed that in each case the average tenacity and ductility were reduced by annealing.

Test No. 292, Table VII, out of the top back plate of a boiler, was made to see what was the relative effect of hand- and of steam-hammer flanging on a plate; and to note the effect of annealing on each.

The breaking-strain of the plate was 25 tons per square inch; the elongation in 8 inches, 25 per cent.; the average drifting-diameter, 0·661 inch; and the average bursting-load 48$\frac{1}{3}$ cwt. Washers were drilled from the edge of the flange up and across the plate to 12 inches from the heel, so as to go through the part likely to be affected by the flanging and by local heating. The average drifting-diameter hand-flanged, unannealed was 0·697 inch, annealed 0·71 inch; average bursting-load on drift, unannealed 44$\frac{4}{9}$ cwt., annealed 44$\frac{8}{9}$ cwt.; for machine-flanging, the average diameter was 0·685 inch unannealed, and 0·71 inch annealed; the average bursting-load 45$\frac{4}{9}$ cwt. unannealed, and 45$\frac{17}{18}$ cwt. annealed. The results are practically identical, and show no advantage of one way of working over another, and no advantage in annealing.

Test No. 228, Table VII, was taken out of the flange of the stiffening-ring of a furnace. The washers unannealed gave an average drifting-diameter of 0·59 inch, annealed 0·583 inch; these being practically identical and showing no advantage in annealing. The results of some other tests are given in their places, both unannealed and annealed, and the Author leaves the question here. So far he has been unable to discover any advantage in annealing the plates he has had to deal with, or any necessity for it.

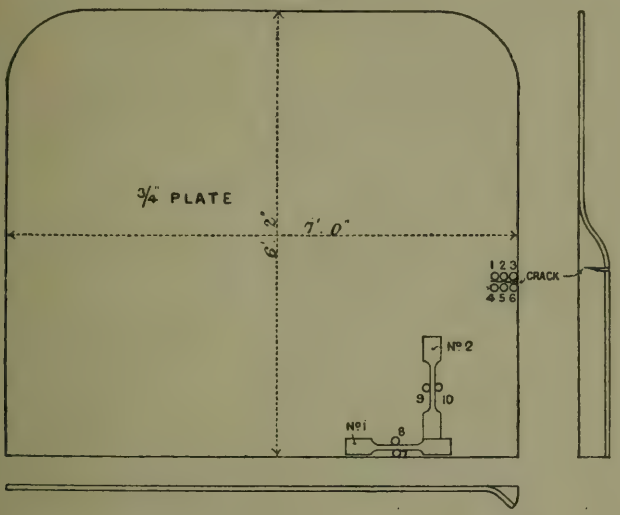
VII. The Effects of Heat, and Tests of Defective Plates.

No branch of investigation connected with steel presents greater difficulties, or has a stronger attraction than this. The Author has endeavoured to confine himself to a statement of facts, and regrets that in the discussion of this branch of the subject, and in its present state, he must, to a certain extent, deal with it speculatively. The lessons to be learned from defective plates are so necessary to a proper consideration of the effects of heat, that he gives a few instances with tests and illustrations.

Test No. 241, Table VIII, Figs. 4, was taken from a back tube-plate of a special quality of steel for furnaces, which cracked in flanging. Scarcely any work had been done on the plate when

it cracked, the flange having only been knocked down to an angle of about 45°. The Author was passing when the plate failed, and he satisfied himself that it was not overheated, had not been allowed to cool locally, and had not been ill-used in any way. Tensile-tests taken lengthways and crosswise showed it

FIGS. 4.

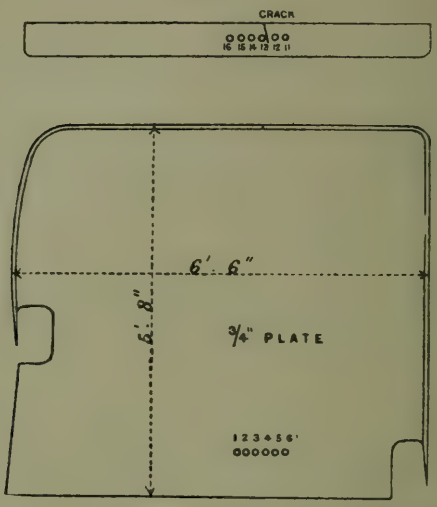


to be a very mild material with an extension of 30 and 27 per cent. in 8 inches, though the extension per inch between the 5th and 7th inches of No. 1 was not quite regular.

Bending-tests were made lengthways and crosswise, the former failing just before the test-piece was bent to the required radius, but the piece cut out to replace it stood the test well. As it was a mere matter of chance whether the good one or the inferior one was taken first, it may be said that the plate stood the required tests. Washers were drilled out near the crack, yet so that no part of it should touch them, and others were taken out of the solid plate near the tensile-test pieces. Those taken from the neighbourhood of the crack drifted to an average of 0·406 inch, whereas they should have drifted to 0·656 inch; three of those out of the solid plate averaged 0·59 inch, and one drifted to 0·75 inch. The drifting-variation of from 0·406 inch to 0·75 inch is equivalent to an elongation in 8 inches of from 4 to 35 per cent. It might have been a matter for surprise if a plate containing such discordant elements had not cracked in flanging.

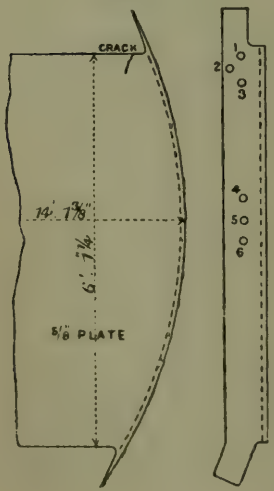
The Author draws attention to this case also because he thinks that the drifting-test is thus shown to give information as to the variations in the plate which is not afforded by the tensile- and bending-tests. Test No. 251, Table VIII, Figs. 5, gives particulars

FIGS. 5.



of a back tube-plate which cracked while being levelled at the plate-furnace. Hammer-marks along the edge of the plate showed that blows had been struck to set the flange square, when the plate was at a low temperature. Washers taken out of the solid plate gave an average drifting-diameter of 0·682 inch, while near the crack they varied from 0·531 inch to 0·75 inch, equal to an elongation of from 18 to 35 per cent. in 8 inches. It seemed as though a strain had been put upon the material at this part owing to unequal contraction, which only required a blow to develop into a fracture.

FIGS. 6.

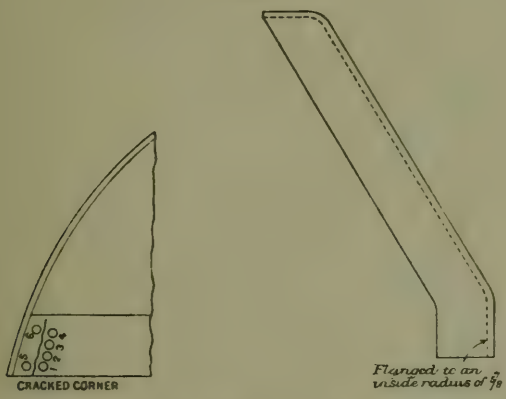


Another test, Figs. 6, was taken from the middle back plate of a boiler which cracked in plating. The plate was welded up, and tests taken from the flange showed a poor average quality,

the drifting-variation being from 0·5 inch to 0·687 inch, equal to an elongation of from 15 to 31 per cent. in 8 inches, the average of six washers being 0·598 inch.

Test No. 286, Table IX, Figs. 7, is an example of a good plate spoilt through the carelessness of a workman; it was the top plate of the back of a boiler, and was cracked in plating at the heel of the flange. It was originally $\frac{5}{8}$ inch thick, but had been

FIGS. 7.



fullered down at one part of the crack to $\frac{7}{16}$ inch, which will account for the deficient bursting-load on the drift.

The tests were as follow:—

Breaking-strain of tensile-test out of solid plate, 25 tons per square inch.
Elongation in 8 inches, per cent. 25.
Average drifting-diameter of washers, out of solid plate, 0·661 inch.

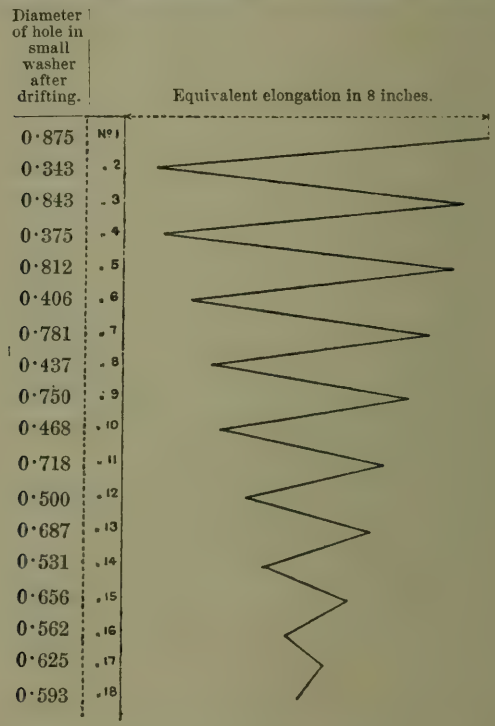
,,	,,	load	,,	,,	,,	48⅓ cwt.
,,	,,	diameter	,,	,, cracked corner,		0·431 inch.
,,	,,	load	,,	,,	,,	25½ cwt.
,,	,,	diameter	,,	corner not cracked,		0·651 inch.
,,	,,	load	,,	,,	,,	41⅛ cwt.

The Author has prepared a diagram, Fig. 8, to illustrate a possible combination and ductility of contiguous particles in a plate, as represented by the equivalent elongation in 8 inches. All these tests have been taken from various plates, though the whole of them are not to be found in one plate. Any pair of them may exist next to each other in a plate, and it seems that such a variation of ductility must be accompanied by a corresponding variation in the modulus of elasticity and linear coefficient of expansion. The Author has not been able to make experiments on these points for want of suitable apparatus. Now if this plate

were locally heated, the strain set up between particles Nos. 2 and 9 (Fig. 8) might be sufficient as in test No. 241 (Table VIII, Figs. 4), to break the plate in flanging; or if the difference was not so great, it might still be as great as between particles Nos. 9 and 14, and, as in test No. 251 (Table VIII, Figs. 5), might only require a blow to break it. The particles of the plate

FIG. 8.

DIAGRAM SHOWING POSSIBLE COMBINATION and DUCTILITY of CONTIGUOUS PARTICLES in a STEEL PLATE DERIVED FROM EXPERIMENTS ON VARIOUS PLATES.



Greatest variation equivalent to from 4 to 45 per cent. in 8 inches.

might be compared to a loaded chain, with links of varying strength, and each link putting a severe strain upon the next one; a blow with a hammer or a slight additional strain would cause the weakest link, that is the one with the least ductility, to break.

Herein lies, so far as the opinion of the Author is concerned, the only remaining difficulty in the use of steel plates, a difficulty

which it is for the steel-makers to remove. If they can, by a thorough mixing of ingredients, make a homogeneous material, very little more will be heard of cracked plates.

In conclusion, the Author gives some tests of plates of a higher tenacity than generally used. The subject is of great importance in view of the increase of working pressures which has taken place of late years, and of the necessity of reducing the weights of boilers for ships of war. He regrets that the plates presented to him for testing purposes were not specially prepared, and do not represent the best results obtainable. It must be remembered that no increase of tensile-strength can be expected unless accompanied by an additional amount of work on the plates. As already explained, this means that the proportion between the thickness of the ingot and the thickness of the plate into which it is rolled is increased. The tensile-strength of a plate is governed by this as well as by the percentage of carbon the plate contains; and not only the tensile-strength but the ductility, which is so important a factor in the manufacture of boilers. Should steel-makers be able to increase the thickness of ingots, and improve the homogeneity of the metal, there is very little doubt but that plates of much higher tenacity could be used than at present. When boiler-plates approach $1\frac{1}{2}$ inch in thickness, boiler-making may be said to approach armour-plating, with very much greater difficulties attached to it.

Before steel came into use there were three qualities of iron plates in a boiler, viz., Yorkshire plates for furnaces, flanging plates for the ends of boilers, and an inferior quality for shell-plates. There is now a special mild quality of plates for furnaces and another quality which is the same for flanging purposes and for the shell-plates. As soon as steel-makers show that they can manufacture a suitable material for the shells of boilers, and the Author entertains no doubt that they can do so, why should not three qualities of steel be brought into use? As shown under the section on hammering, shell-plates for boilers with butt-straps can be bent without any application of heat or hammering, and this should remove the difficulties which have hitherto stood in the way. When mild steel was introduced as a new material about eleven years ago, and with the appliances and modes of working then in vogue, it was doubtless right to insist upon the stringent tests then considered necessary. The tempered bending-test for shell-plates would not, under the altered conditions, be so important as it was then; and, by gradual steps, there is little doubt but that a considerable increase of tenacity might

be attained. At the same time, in view of the great variation between different parts of the same plate, it would be advisable that some uniform width should be specified for the samples tested, and that some stipulation should be made as to the minimum proportion to be allowed between the breaking-strain and permanent set. The Author has been favoured by Mr. E. D. Leavitt, jun., of Cambridgeport, Mass., with a specification and records of tests of steel boiler-plates as made and used there. It is stipulated that "All plates are to be open-hearth steel, and to have an elastic limit of not less than 37,000 lbs. per square inch (16·52 tons), an ultimate strength of not less than 53,000 lbs. (23·66 tons), nor more than 61,000 lbs. per square inch (27·23 tons), and an elongation of not less than 20 per cent. in 15 inches." The average results of one hundred and eighty-three tests were as follow:—

Breaking-strain	26·36 tons per square inch.
Elastic limit	18·42 ,, ,,
Contraction of area at fracture . .	45·00 per cent.
Elongation in 15 inches	23·38 ,,

Equivalent to about 24 per cent. in 10 inches and 25 per cent. in 8 inches. The average elastic limit was equal to 70 per cent. of the average breaking-strain, whereas in specimens tested by the Author it has been as low as 48 per cent. and has never exceeded 66 per cent.

When boilers are built with a factor of safety of 5, and are tested to double the working pressure, which is equal to 40 per cent. of the ultimate strength, 70 per cent. cannot be too high for the elastic limit, and 60 per cent. should be a minimum.

As far as the experience of the Author goes, there has been little or no improvement in the quality of steel plates during the last eleven years; the question is, are steel-makers to be satisfied with the progress already made, or are they to strive after a further advance? As the tests Nos. 245 and 246 of plates of high tenacity (Table X) do not represent what the Author considers the best results obtainable, he does not make any further remarks upon them, but simply gives the details.

Lest it should be thought that anything in the present Paper might lead to the conclusion that the Author regrets the age of iron, he is of opinion that no one who has used steel would wish to revert to iron, and he gives a record of his experience in a list of rejected and spoilt steel plates he has used since steel was introduced for boiler-making purposes in 1875, as compared with a corresponding number of iron plates.

Total number of iron plates used			4,464
,, ,, steel ,, ,, ...			4,236
Number of iron plates defective . . .	120	percentage	2·68
,, steel ,, ,, . . .	44	,,	1·04
,, iron plates spoilt in working .	9	,,	0·2
,, steel ,, ,, ,, .	29	,,	0·68

This list does not include two parcels of steel plates and two of iron rejected in bulk. Allowing for a certain number of steel plates spoilt, owing to the inexperience of workmen in using a new material, the results may be considered very satisfactory; and when it is stated that no instance has occurred in the four thousand two hundred and thirty-six steel plates where a failure has taken place after the boilers have been in use, the evidence in favour of steel may be said to be conclusive.

The Paper is accompanied by numerous diagrams, from which the Figs. in the text have been prepared.

APPENDIX.

TABLE I.—Washers, $\frac{11}{16}$ inch in diameter; hole, $\frac{15}{64}$ inch.

Number of Washer.	Washer $\frac{13}{16}$ inch thick.		Washer 0·391 inch thick.				Washer 0·25 inch thick.					
	Hole drifted to		Hole drifted to				Hole drifted to					
	Unannealed.	Annealed.	Unannealed.		Annealed.		Unannealed.			Annealed.		
			Top.	Bottom.	Top.	Bottom.	Top.	Middle.	Bottom.	Top.	Middle.	Bottom.
	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.
1	$\frac{17}{32}$	$\frac{5}{8}$	$\frac{1}{2}$	$\frac{7}{16}$	$\frac{17}{32}$	$\frac{19}{32}$	$\frac{9}{16}$	$\frac{5}{8}$	$\frac{1}{2}$	$\frac{17}{32}$	$\frac{9}{16}$	$\frac{17}{32}$
2	$\frac{9}{16}$	$\frac{21}{32}$	$\frac{9}{16}$	$\frac{9}{16}$	$\frac{17}{32}$	$\frac{9}{16}$	$\frac{17}{32}$	$\frac{9}{16}$	$\frac{9}{16}$	$\frac{9}{16}$	$\frac{19}{32}$	$\frac{5}{8}$
3	$\frac{11}{16}$	$\frac{21}{32}$	$\frac{5}{8}$	$\frac{19}{32}$	$\frac{9}{16}$	$\frac{5}{8}$	$\frac{9}{16}$	$\frac{17}{32}$	$\frac{15}{32}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{19}{32}$
4	$\frac{21}{32}$	$\frac{21}{32}$	$\frac{9}{16}$	$\frac{19}{32}$	$\frac{21}{32}$	$\frac{19}{32}$	$\frac{15}{32}$	$\frac{19}{32}$	$\frac{15}{32}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{19}{32}$
5	$\frac{23}{32}$	$\frac{21}{32}$	$\frac{5}{8}$	$\frac{17}{32}$	$\frac{17}{32}$	$\frac{13}{32}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{17}{32}$	$\frac{19}{32}$	$\frac{15}{32}$
6	$\frac{21}{32}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{21}{32}$	$\frac{9}{16}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{17}{32}$	$\frac{9}{16}$	$\frac{1}{2}$	$\frac{19}{32}$	$\frac{19}{32}$
7	..	..	$\frac{17}{32}$	$\frac{21}{32}$	..	..	..	..	..	..	..	..
8	..	..	$\frac{5}{8}$	$\frac{11}{16}$	..	..	..	..	..	..	..	..
9	..	..	$\frac{11}{16}$	$\frac{5}{8}$	..	..	..	..	..	..	..	..
10	..	..	$\frac{5}{8}$	$\frac{1}{2}$	..	..	..	..	..	..	..	..
Average . .	0·645	0·645	0·59		0·554		0·535			0·555		
Largest . .	$\frac{23}{32}$	$\frac{21}{32}$	$\frac{11}{16}$		$\frac{21}{32}$		$\frac{5}{8}$			$\frac{5}{8}$		
Smallest . .	$\frac{17}{32}$	$\frac{5}{8}$	$\frac{7}{16}$		$\frac{13}{32}$		$\frac{15}{32}$			$\frac{15}{32}$		
Variation of Elongation per cent. .	37·97 to 18·28	28·13 to 25 31	30·94 to 11·25		28·13 to 8·44		25·31 to 12·66			25·31 to 12·66		

N.B.—Top, middle, bottom, refer to the original position of the washer in the plate.

TABLE II.—Washers, $\frac{11}{16}$ inch in diameter; hole, $\frac{15}{64}$ inch.

Number of Washer.	Washer $\frac{1}{4}$ inch thick.				Washer $\frac{3}{8}$ inch thick.			
	Hole drifted to				Hole drifted to			
	Lengthways.		Crosswise.		Lengthways.		Crosswise.	
	Unannealed.	Annealed.	Unannealed.	Annealed.	Unannealed.	Annealed.	Unannealed.	Annealed.
	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.
1	$\frac{7}{16}$	$\frac{15}{32}$	$\frac{17}{32}$	$\frac{17}{32}$	$\frac{15}{32}$	$\frac{7}{16}$	$\frac{7}{16}$	$\frac{15}{32}$
2	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{17}{32}$	$\frac{15}{32}$	$\frac{1}{2}$	$\frac{13}{32}$	$\frac{7}{16}$
3	$\frac{13}{32}$	$\frac{17}{32}$	$\frac{15}{32}$	$\frac{9}{16}$	$\frac{15}{32}$	$\frac{7}{16}$	$\frac{13}{32}$	$\frac{15}{32}$
4	$\frac{7}{16}$	$\frac{15}{32}$	$\frac{1}{2}$	$\frac{7}{16}$	$\frac{15}{32}$	$\frac{7}{16}$	$\frac{7}{16}$	$\frac{7}{16}$
5	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{17}{32}$	$\frac{7}{16}$	$\frac{15}{32}$	$\frac{13}{32}$	$\frac{7}{16}$	$\frac{13}{32}$
6	$\frac{7}{16}$	$\frac{15}{32}$	$\frac{15}{32}$	$\frac{15}{32}$	$\frac{15}{32}$	$\frac{7}{16}$	$\frac{15}{32}$	$\frac{15}{32}$
Average .	0·432	0·489	0·5	0·494	0·468	0·442	0·432	0·447
Largest .	$\frac{7}{16}$	$\frac{17}{32}$	$\frac{17}{32}$	$\frac{9}{16}$	$\frac{15}{32}$	$\frac{1}{2}$	$\frac{15}{32}$	$\frac{15}{32}$
Smallest .	$\frac{13}{32}$	$\frac{15}{32}$	$\frac{15}{32}$	$\frac{7}{16}$	$\frac{13}{32}$	$\frac{13}{32}$	$\frac{13}{32}$	$\frac{13}{32}$
Variation of Elongation per cent. .	11·25 to 8·44	18·28 to 12·66	18·28 to 12·66	21·09 to 11·25	12·66 to 8·44	15·47 to 8·44	12·66 to 8·44	12·66 to 8·44

TABLE III.—SHELL-PLATES $\frac{13}{16}$ INCH THICK.

Mean of three Tests.	$1\frac{9}{16}$ inch long.						8 inches long.	
	Middle half of Plate.		Full thickness of Plate.		Top half of Plate.		Full thickness of Plate.	
	Unannealed.	Annealed.	Unannealed.	Annealed.	Unannealed.	Annealed.	Unannealed.	Annealed.
Section tested, inch	0·37×0·23	0·42×0·23	0·812×0·219	0·812×0·23	0·364×0·23	0·41×0·23	0·812×0·234	0·81×0·23
Area tested in sq. ins.	0·0846	0·0966	0·178	0·185	0·0837	0·095	0·1904	0·1869
Elasticity began, tons	..	..	..	..	..	..	1·41	1·36
Elasticity began, tons per sq. inch	..	..	..	..	..	..	9·18	7·36
Permanent set began, tons	..	..	..	..	..	..	2·68	2·7
Permanent set began, tons per sq. inch	..	..	..	..	..	..	14·09	14·35
Broke at, tons	2·3	2·57	5·18	5·13	2·29	2·61	5·11	5·1
Broke at, tons per square inch	27·34	26·74	29·11	28·35	27·34	27·71	26·87	27·45
Size of fracture, inch	0·24×0·16	0·29×0·15	0·562×0·156	0·588×0·15	0·252×0·17	0·29×0·15	0·562×0·156	0·58×0·17
Reduction of area, per cent.	45·04	55·41	50·62	52·02	49·59	53·57	45·3	48·95
Elongation in length, inch	0·52	0·53	0·55	0·54	0·46	0·5	1·94	1·79
Elongation in length, per cent.	33	34	35	34	30	32	24·73	22·38
Variations. Breaking-strain tons per sq. in.	27·03 to 27·61	26·4 to 27·43	28·93 to 29·5	27·02 to 30·23	27·18 to 27·48	27·46 to 28·1	26·52 to 27·3	26·5 to 28·1
Variations. Reduction of area, per cent.	43·01 to 47	50·3 to 59·4	50·62	48·85 to 53·6	45·8 to 52·12	50·8 to 57·05	43·6 to 46·16	42·5 to 52·2
Variations. Elongation, per cent.	32 to 36	32 to 36	34 to 36	32 to 36	28 to 32	32	21·8 to 28·1	21·09 to 23·8

TABLE III *continued.*—SHEARING-TESTS.

Double Shear.	Lengthways.	Crosswise.
Section tested diameter, inch	$\frac{3}{4}$	$\frac{3}{4}$
Area tested, square inch	0·4417	0·4417
Breaking-strain, tons per square inch .	19·8 to 20·66	19·75 to 20·72
Breaking-strain, tons	17·5 to 18·25	17·45 to 18·3

TABLE IV.—LAP-WELDS ANNEALED, HOLES $2\frac{1}{4}$ INCHES PITCH.

	Flanged Stiffening-rings of Furnaces.					Flanged Stiffening-ring.	
	Holes drifted to					Test 284.	
Number of Tests .	247	254	256	271	274	Hole Drifted to	Greatest pressure on Drifts.
	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Cwt.
No. of washer 1	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{19}{32}$	$\frac{9}{16}$	38
2	$\frac{5}{8}$	$\frac{19}{32}$	$\frac{15}{32}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{19}{32}$	35
3	$\frac{17}{32}$	$\frac{13}{32}$	$\frac{13}{32}$	$\frac{17}{32}$	$\frac{23}{32}$	$\frac{5}{16}$	18
4	$\frac{5}{16}$	$\frac{7}{16}$	$\frac{5}{8}$	$\frac{21}{32}$	$\frac{11}{32}$	$\frac{1}{2}$	31
5	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{9}{16}$	$\frac{9}{16}$	35
6	$\frac{21}{32}$	$\frac{11}{16}$	$\frac{5}{8}$	$\frac{11}{16}$	$\frac{11}{16}$	$\frac{5}{8}$	35

N.B.—The black lines show the centre of the weld.

TENSILE-TESTS.

Number of Test.	247		254		256		271		274	
Section tested, inch . . .	0·663	0·670	0·665	0·683	0·614	0·567	0·653	0·663	0·671	0·671
Breaking-strain per ton per square inch .	26·3	27·6	27·6	27·7	26·5	26·3	26·4	26·6	26·3	26·2
Elongation per cent. in 8 inches	29	22	27	22	27	23	21	27	25	23

TABLE V.—HAMMERING.

All Washers, $\frac{11}{16}$ inch in diameter; hole, $\frac{15}{64}$ inch in diameter.

Number of Test	224.		272.				277.				285.			
	Unannealed.		Unannealed.				Unannealed.		Annealed.		Unannealed.		Annealed.	
Hole drifted to	N. H.	H.	No. 1 Plate.		No. 2 Plate.		N. H.	H.	N. H.	H.	N. H.	H.	N. H.	H.
			N. H.	H.	N. H.	H.								
Smallest	Inch. $\frac{20}{32}$	Inch. $\frac{14}{32}$	Inch $\frac{19}{32}$	Inch. $\frac{15}{32}$	Inch. $\frac{17}{32}$	Inch. $\frac{14}{32}$	Inch. $\frac{5}{8}$	Inch. $\frac{7}{16}$	Inch. $\frac{19}{32}$	Inch. $\frac{15}{32}$	Inch. $\frac{19}{32}$	Inch. $\frac{1}{2}$	Inch. $\frac{19}{32}$	Inch. $\frac{9}{16}$
Largest	$\frac{23}{32}$	$\frac{23}{32}$	$\frac{23}{32}$	$\frac{11}{16}$	$\frac{21}{32}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{23}{32}$	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{23}{32}$	$\frac{11}{16}$	$\frac{23}{32}$	$\frac{11}{16}$
Average	0·666	0·564	0·656	0·585	0·589	0·545	0·648	0·571	0·656	0·531	0·651	0·589	0·696	0·625
Equivalent reduction per cent. of elongation in 8 inches	7·89		6·01		2·74		5·94		9·85		5·34		5·63	

N.B.—N. H. and H. mean "not hammered" and "hammered" respectively.

TABLE V *continued.*—COMPRESSION

Plate, $\frac{13}{16}$ inch thick.

Number of Washer.	Cut from Burrs $1\frac{1}{16}$ inch in Diameter at Top $1\frac{1}{4}$ inch at Bottom.				Cut from squeezed Plate.	
	Unannealed.		Annealed.		Unannealed.	
	Hole drifted to	Greatest pressure on Drift.	Hole drifted to	Greatest pressure on Drift.	Hole drifted to	Greatest pressure on Drift.
	Inch.	Cwt.	Inch.	Cwt.	Inch.	Cwt.
1	$\frac{19}{32}$	63·0	$\frac{17}{32}$	57·0	$\frac{21}{32}$	64·0
2	$\frac{21}{32}$	62·0	$\frac{21}{32}$	59·0	$\frac{2}{4}$	59·0
3	$\frac{23}{32}$	62·0	$\frac{21}{32}$	60·0	$\frac{19}{32}$	59·0
4	$\frac{19}{32}$	63·0	$\frac{5}{8}$	63·0	$\frac{23}{32}$	59·0
5	$\frac{11}{16}$	63·0	$\frac{19}{32}$	61·0	$\frac{23}{32}$	57·0
6	$\frac{5}{8}$	62·0	$\frac{5}{8}$	61·0	$\frac{11}{16}$	59·0
Average	0·645	62·5	0·614	60·1	0·687	59·5

TABLE VI.—FLANGING.

Test 287.			Test 233.				Test 278.	
Number of Washer.	Hole drifted to	Pressure on drift.	Washers drifted to	Hammered.		Scarfed.		Proper heat.	Overheated.
				Thin corner.	Flange.	Thin corner.	Flange.	Eight Washers.	Sixteen Washers.
								Size.	Size.
	Inch.	Cwt.		Inch.	Inch.	Inch.	Inch.	Inch.	Inch.
1	$\frac{5}{8}$	66	Largest	$\frac{3}{4}$	$\frac{23}{32}$	$\frac{21}{32}$	$\frac{21}{32}$	$\frac{25}{32}$	$\frac{23}{32}$
2	$\frac{9}{16}$	69	Smallest	$\frac{17}{32}$	$\frac{13}{32}$	$\frac{19}{32}$	$\frac{13}{16}$	$\frac{9}{16}$	$\frac{9}{16}$
3	$\frac{1}{2}$	59	Average	0·656	0·679	0·621	0·695	0·683	0·656
4	$\frac{5}{8}$	59							
5	$\frac{1}{2}$	71							
6	$\frac{5}{8}$	78							
7	$\frac{5}{8}$	66							
8	$\frac{11}{16}$	71							
9	$\frac{21}{32}$	71							

Washers all annealed.

Table VII.—Annealing.

Washers, $\frac{11}{16}$ inch in diameter; hole, $\frac{15}{64}$ inch in diameter

Test No. 290.																	
Nos. of Washers.	Washers taken from	Unannealed.								Annealed.							
		Largest.			Smallest.			Average.		Largest.			Smallest.			Average.	
		No. of Washer.	Size.	Pressure on Drift.	No. of Washer.	Size.	Pressure on Drift.	Size.	Pressure on Drift.	No. of Washer.	Size.	Pressure on Drift.	No. of Washer.	Size.	Pressure on Drift.	Size.	Pressure on Drift.
			Inch.	Cwt.		Inch.	Cwt.	Inch.	Cwt.		Inch.	Cwt.		Inch.	Cwt.	Inch.	Cwt.
1 to 6	Solid plate . . .	5	$\frac{3}{4}$	40	1 and 2	$\frac{11}{16}$	41	0·732	$41\frac{1}{6}$	3	$\frac{25}{32}$	40	2	$\frac{21}{32}$	40	0·703	$40\frac{1}{2}$
7 ,, 28	Flanged part . .	8	$\frac{3}{4}$	43	15	$\frac{17}{32}$	35	0·625	$38\frac{1}{2}$	26	$\frac{3}{4}$	40	12	$\frac{1}{2}$	33	0·634	$37\frac{9}{22}$
29 ,, 35	,, ,,	32, 35	$\frac{23}{32}$	$38\frac{1}{2}$	29	$\frac{5}{8}$	37	0·677	$40\frac{5}{7}$	32	$\frac{3}{4}$	39	35	$\frac{19}{32}$	40	0·638	$38\frac{6}{7}$
36 ,, 40	,, ,,	40	$\frac{23}{32}$	40	38	$\frac{5}{8}$	41	0·587	$41\frac{2}{5}$	40	$\frac{5}{8}$	40	39	$\frac{19}{32}$	37	0·606	$38\frac{1}{5}$
41 ,, 62	,, ,,	42, 49	$\frac{3}{4}$	43	60	$\frac{19}{32}$	40	0·662	$42\frac{17}{22}$	57	$\frac{3}{4}$	40	61	$\frac{9}{16}$	41	0·636	$38\frac{19}{22}$
1 ,, 13	Across weld not flanged . .	2, 3, 4	$\frac{23}{32}$	41	7	$\frac{13}{32}$	43	0·647	$44\frac{4}{13}$	1	$\frac{25}{32}$	42	8	$\frac{1}{2}$	42	0·567	$41\frac{9}{13}$

TABLE VII *continued*.—ANNEALING.

Hole drifted to	Test No. 292.								Test No. 228.	
	Hand-Flanging.				Machine-Flanging.				Holes drifted to	
	Unannealed.		Annealed.		Unannealed.		Annealed.		Unannealed.	Annealed.
	Size.	Pressure on Drift.	Size.	Pressure on Drift.	Size.	Pressure on Drift.	Size.	Pressure on Drift.		
	Inch.	Cwt.	Inch.	Cwt.	Inch.	Cwt.	Inch.	Cwt.	Inch.	Inch.
Largest	$\frac{3}{4}$	45	$\frac{23}{32}$	45	$\frac{23}{32}$	48	$\frac{3}{4}$	49	$\frac{23}{32}$	$\frac{3}{4}$
Smallest	$\frac{9}{16}$	43	$\frac{19}{32}$	46	$\frac{19}{32}$	47	$\frac{5}{8}$	43	$\frac{7}{16}$	$\frac{17}{32}$
Average	0·697	$44\frac{4}{9}$	0 71	$44\frac{8}{9}$	0·685	$45\frac{4}{9}$	0·71	$45\frac{17}{18}$	0·59	0·583
No. of washers tested	18	..	18	..	18	..	18	..	9	9

TABLE VIII.—HEAT, &c.

Test 241.							Test 251.	
Tensile-Test.					Drifting.		Drifting.	
——	No. 1.	No. 2.	Elongation per Inch. No. 1.	Elongation per Inch. No. 2.	Number of Washer.	Hole drifted to	Number of Washer.	Hole drifted to
Section tested, inch . . .	0·89×0·75	0·88×0·75	1st inch 0·16	1st inch 0·18	1	Inch. $\frac{13}{32}$	1	Inch. $\frac{21}{32}$
Area in square inch . . .	0·6675	0·66	2nd ,, 0·23	2nd ,, 0·24	2	$\frac{11}{32}$	2	$\frac{21}{32}$
Elasticity began . . tons	5·5	4·5	3rd ,, 0·75 broke	3rd ,, 0·31	3	$\frac{15}{32}$	3	$\frac{21}{32}$
,, tons per sq. in. . .	8·24	6·82	4th ,, 0·27	4th ,, 0·56 broke	4	$\frac{7}{16}$	4	$\frac{21}{32}$
Permanent set began . tons	8·8	7·0	5th ,, 0·31	5th ,, 0·29	5	$\frac{13}{32}$	5	$\frac{3}{4}$
,, ,, tons per sq. in.	13·18	10·61	6th ,, 0·18	6th ,, 0·24	6	$\frac{3}{8}$	6	$\frac{23}{32}$
Broke at . . . . tons	16·25	16·0	7th ,, 0·34	7th ,, 0·23	7	$\frac{15}{32}$	11	$\frac{17}{32}$
,, tons per sq in. . .	24·34	24·24	8th ,, 0·16	8th ,, 0·17	8	$\frac{17}{32}$	12	$\frac{5}{8}$
Size at fracture . . . inch	$\frac{5}{8}\times\frac{1}{2}$	$\frac{11}{16}\times\frac{9}{16}$			9	$\frac{17}{32}$	13	$\frac{7}{16}$
Reduction of area per cent. .	53·2	41·4			10	$\frac{3}{4}$	14	$\frac{5}{8}$
Elongation in 8 inches. . .	$2\frac{13}{32}$	$2\frac{7}{32}$					15	$\frac{5}{8}$
,, . . . per cent.	30·08	27·73					16	$\frac{3}{4}$
					Average	0·471	Average	0·64

TABLE IX.—HEAT, &c.

Test No. 286.

Drifting-Tests, Unannealed.

Number of Washer.	Solid Plate.		Cracked Corner.		Solid Corner.	
	Hole drifted to	Pressure on Drift.	Hole drifted to	Pressure on Drift.	Hole drifted to	Pressure on Drift.
	Inch.	Cwt.	Inch.	Cwt.	Inch.	Cwt.
1	$\frac{23}{32}$	48	$\frac{7}{16}$	29	$\frac{11}{16}$	46
2	$\frac{3}{4}$	48	$\frac{7}{16}$	30	$\frac{11}{16}$	42
3	$\frac{17}{32}$	48	$\frac{15}{32}$	27	$\frac{23}{32}$	43
4	$\frac{5}{8}$	47	$\frac{7}{16}$	27	$\frac{25}{32}$	42
5	$\frac{11}{16}$	51	$\frac{3}{8}$	16	$\frac{11}{16}$	43
6	$\frac{21}{32}$	48	spoilt	..	$\frac{19}{32}$	40
7	..	..	..	..	$\frac{11}{16}$	43
8	..	..	..	..	$\frac{5}{8}$	44
9	..	..	..	..	$\frac{19}{32}$	40
10	..	..	..	..	$\frac{5}{8}$	40
11	..	..	..	..	spoilt	..
12	..	..	..	..	$\frac{5}{8}$	43
13	..	..	..	..	$\frac{19}{32}$	39
14	..	..	..	..	$\frac{19}{32}$	39
15	..	..	..	..	$\frac{11}{16}$	38
Average	0·661	48⅓	0·431	25⅘	0·651	41⅐

Tensile-test, Annealed.

		Elongation per Inch.
Section tested . . . . . inch	$1 \times \frac{39}{64}$	1st inch 0·14
Area „ . . . . . sq. in.	0·609	2nd „ 0·25
Elasticity began . . . . . tons	2·5	3rd „ 0·61 broke
„ tons per square inch	4·1	4th „ 0·29
Permanent set began . . . . . tons	7·0	5th „ 0·21
„ „ tons per square inch . . .	11·49	6th „ 0·19
Broke at . . . . . tons	15·25	7th „ 0·16
„ tons per square inch	25·04	8th „ 0·15
Size at fracture . . . . . inch	$\frac{11}{16} \times \frac{3}{8}$	
Reduction of area . . . . . per cent.	57·67	
Elongation in 8 inches	2	
„ . . . . . per cent.	25	

Table X.—Heat, &c.

Drifting-Tests.

Number of Washers.	Washers 1 inch thick.				Washers 0·484 inch thick.								Washers 0·3125 inch thick.											
	Test 245.		Test 246.		Test 245.				Test 246.				Test 245.						Test 246.					
	Unannealed.	Annealed.	Unannealed.	Annealed.	Unannealed.		Annealed.		Unannealed.		Annealed.		Unannealed.			Annealed.			Unannealed.			Annealed.		
					T.	B.	T.	B.	T.	B.	T.	B.	T.	M.	B.	T.	M.	B.	T.	M.	B.	T.	M.	B.
	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch	Inch.
1	17/32	9/16	9/16	17/32	15/32	1/2	17/32	15/32	7/16	7/16	17/32	17/32	7/16	7/16	15/32	13/32	7/16	15/32	7/16	7/16	7/16	7/16	7/16	1/2
2	15/32	31/32	1/2	17/32	7/16	1/2	15/32	15/32	17/32	7/16	1/2	17/32	13/32	1/2	17/32	15/32	7/16	15/32	7/16	15/32	7/16	7/16	13/32	7/16
3	17/32	5/8	1/2	17/32	1/2	7/16	15/32	7/16	15/32	15/32	7/16	1/2	15/32	1/2	1/2	1/2	13/32	7/16	7/16	7/16	7/16	15/32	7/16	13/32
4	19/32	17/32	15/32	9/16	1/2	9/16	15/32	17/32	17/32	1/2	1/2	15/32	13/32	1/2	15/32	15/32	13/32	15/32	1/2	15/32	1/2	15/32	13/32	7/16
5	1/2	17/32	17/32	9/16	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
6	9/16	5/8	5/8	9/16	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
7	7/16	7/16	17/32	7/16	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
8	19/32	17/32	7/16	15/32	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Average	0·527	0·562	0·519	0·523	0·489		0·48		0·476		0·5		0·468			0·453			0·453			0·453		

Note.—T. B. M. means top, bottom and middle respectively. See note to Table I.

—	Test 245.								Test 246.							
	Crosswise.				Lengthways.				Crosswise.				Lengthways.			
	Unannealed.		Annealed.		Unannealed.		Annealed.		Unannealed.		Annealed.		Unannealed.		Annealed.	
		Elongation Per Inch.		Elongation Per Inch.		Elongation Per Inch.		Elongation Per Inch.		Elongation Per Inch.		Elongation Per Inch.		Elongation Per Inch.		Elongation Per Inch.
Section tested inch	1×1	Inch. 1st 0·17	1×1	Inch. 1st 0·11	1×1	Inch. 1st 0·15	1×1	Inch. 1st 0·15	1×1	Inch. 1st 0·15	1×1	Inch. 1st 0·23	1×1	Inch. 1st 0·07	1×1	Inch. 1st 0·13
Area in sq. inches	1	2nd 0·26 broke	1	2nd 0·10	1	2nd 0·44 broke	1	2nd 0·14	1	2nd 0·17	1	2nd 0·60 broke	1	2nd 0·07	1	2nd 0·18
Elasticity began, tons	9	3rd 0·18	5·5	3rd 0·10	5	3rd 0·22	3	3rd 0·13	9	3rd 0·11	10	3rd 0·16	15	3rd 0·10	5	3rd 0·22
Ditto, tons per sq. inch	9	4th 0·13	5·5	4th 0·10	5	4th 0·10	3	4th 0·16	9	4th 0·11	10	4th 0·08	15	4th 0·09	5	4th 0·46 broke
Permanent set began, tons	17·5	5th 0·13	14·75	5th 0·12	15	5th 0·17	16·75	5th 0·16	16·5	5th 0·09	16·5	5th 0·07	16	5th 0·10	19·75	5th 0·16
Ditto, tons per sq. inch	17·5	6th 0·14	14·75	6th 0·14	15	6th 0·17	16·75	6th 0·19	16·5	6th 0·06	16·5	6th 0·06	16	6th 0·22	19·75	6th 0·14
Broke at, tons	34·25	7th 0·14	33	7th 0·28	32·75	7th 0·17	33	7th 0·55 broke	35	7th 0·07	32·5	7th 0·05	31·75	7th 0·36 broke	35·25	7th 0·11
Ditto, tons per sq. inch	34·25	8th 0·10	33	8th 0·46 broke	32·75	8th 0·14	33	8th 0·20	35	8th 0·04 broke	32·5	8th 0·03	31·75	8th 0·11	35·25	8th 0·10
Size at fracture, inch	$\frac{29}{32}\times\frac{29}{32}$	..	$\frac{49}{64}$ sq.	..	$\frac{25}{32}\times\frac{13}{16}$	..	$\frac{49}{64}\times\frac{47}{64}$	..	$1\times\frac{63}{64}$	..	$\frac{3}{4}\times\frac{3}{4}$	..	$\frac{13}{16}\times\frac{51}{64}$	..	$\frac{25}{32}\times\frac{13}{16}$	..
Reduction of area p. cent.	17·92	..	41·38	..	36·54	..	43·77	..	1·56	..	43·75	..	35·25	..	36·52	..
Elongation in 8 inches	$1\frac{1}{4}$	..	$1\frac{13}{32}$	..	$1\frac{21}{32}$	..	$1\frac{21}{32}$	..	$\frac{13}{16}$	..	$1\frac{9}{32}$	..	$1\frac{1}{8}$	..	$1\frac{1}{2}$	..
Elongation per cent.	15·625	..	17·58	..	20·7	..	20·7	..	10·15	..	16·02	..	14·06	..	18 75	..
	Stood unquenched bending, but not quenched test.								Did not stand bending test, quenched or unquenched.							

Discussion.

Mr. Bruce. Mr. G. B. Bruce, President, said that as the Author of the Paper was dead, it could not be made the subject of the usual vote of thanks; but he hoped that the discussion which would follow would secure to the lamented Author, Mr. Hamilton Goodall, an honourable place in the archives of the Institution as an earnest, industrious, practical worker in an important department of engineering.

Mr. Wells. Mr. Sidney H. Wells stated that his business connection with the Author ended before the experiments described in the Paper were begun, and the time he had been collecting information upon the subject was very limited. He had, however, recently worked it up and got together the test-pieces, in order that the Institution might suffer as little as possible by the Author's death. In the absence of any more direct representative of the Author, he would watch the discussion, and, if necessary, give any further information that he might possess, or be able to obtain.

Mr. Ellis. Mr. J. D. Ellis observed that in consequence of the death of the Author of the Paper the members were placed in a rather difficult position, but he was sure that any criticisms they might offer would be taken by those representing the Author in the most friendly spirit. The first portion of the Paper alluded chiefly to some experiments of the Author with regard to taking out washers and punching them. He had certainly been at immense trouble in doing so, and for some purposes perhaps his process of testing might be of value. But when the excellent manner in which machinists had supplied engineers with machines for getting ready the test-pieces was considered, and the splendid machines for testing them, they would hardly be inclined to abandon such tests in order to adopt the one mentioned by the Author. While that test gave the extension to a certain extent, it did not give in any way the permanent set; it did not give the tensile-strain, nor the elongation nor reduction of area. The tensile-strain test would, therefore, he thought, be still considered as the most valuable. On the subject of annealing he differed entirely from the Author. Had annealing been adopted, the Author would have found that many difficulties with which he had to contend would have vanished; he certainly would not have found that one portion of a plate would have been as soft as lead, while the other, when punched, would have gone off like a pistol. All plates which had not to be heated all over in the future process of manufacture should, he

thought, most certainly be annealed. Any one who had spent, as he had, years in a steel rolling-mill, and had seen that, however careful the workmen might be, the metal would at times be finished at very different degrees of heat, could hardly help acknowledging the desirability of bringing all those pieces of metal into the same heat again before they were used. Of course that did not apply to the sheets of steel which had to be afterwards heated all over. The Author had asked if a steel plate was damaged by local heating? Undoubtedly it was. He also asked: "If damaged, is it restored wholly or partially to its original strength and ductility by annealing?" Of that also he thought there could be no doubt. He further asked whether tests had been made to determine those points? Mr. Ellis's firm had made a large number of plates with a view of satisfying themselves on the subject, and he thought there could be no doubt with reference to it. The Author went on to say that the breaking-strain was sometimes increased and sometimes diminished by annealing. As a rule it was somewhat diminished, but very little, and a great deal more regularity was attained when the plate had been annealed than there was before. The Paper also stated that it was not necessary to anneal iron plates, and the Author concluded that it was not necessary to anneal steel plates. He could scarcely agree with him on that point. Iron plates were of course formed of material to a certain extent fibrous; but steel being generally homogeneous, and having a considerable amount of carbon, was more affected by cooling than iron, and therefore required to be annealed, while iron did not need it to the same extent. He made the steel plates for the blockade runners during the American War, and he had made steel plates ever since; and his experience certainly was that the plates should, if possible, be annealed. The Author had stated: "It must be remembered that no increase of tensile-strength can be expected unless accompanied by an additional amount of work on the plates;" and elsewhere he spoke of the desirability of plates being rolled out of much thicker pieces of steel. In fact, he almost went so far as to say that it was impossible to make good plates without having the ingots very thick. No doubt up to a certain point it was desirable, in order to get good plates, that the ingot should be of considerable thickness, say, for a $\frac{1}{2}$-inch plate, 12 or 14 inches; but that did not affect the tensile-strain. His firm was at present making plates for some boilers for the London, Brighton and South Coast Railway, 9 feet wide, 28 feet long, and $1\frac{1}{16}$ inch thick, and weighing over 5 tons. For such a size, a very large ingot was of course

Mr. Ellis.

Mr. Ellis. necessary. The ingot was 4 feet wide, 3 feet thick, and 8 or 10 feet long. The plate had to be able to bear not less than 28 tons tensile-strain, and not more than 30 tons. It was therefore absolutely necessary, before making the ingot into a plate, to ascertain that it was of exactly the right temper. For that purpose a small ingot about 14 inches square was prepared and hammered down into a slab of about 6 inches, and then rolled to the size required to test it. If it was between 28 and 30 tons the large ingot was used, and put under a 4,000-ton press, where it was pressed down to 14 inches thick and 8 feet long, and then rolled at one heat to the size required. The plate which had been pressed down from 3 feet thick and afterwards rolled to $1\frac{1}{16}$ foot, gave exactly the same tensile-strain as the smaller ingot previously made. That showed pretty plainly that beyond a certain point a greater than the ordinary tensile-strain was not obtained. But he believed the material was better, clearer, sounder, and of very excellent quality. It might be inferred from the Paper that the steel used in the present day was not a very reliable material; but he thought that was a great mistake. It was alleged that during the last eleven years no advance had been made in the manufacture of steel plates; but there again he differed from the Author. There could be no doubt that within the last year or two the manufacture of plates had considerably improved. Eleven years ago his firm began to use ferro-manganese with a very high percentage of manganese, and from that time had made excellent and trustworthy plates; having constructed during the last five years upwards of four thousand very large boiler-steel front-plates, flanged at one heat all the way round, and without a single failure. With such a result it could hardly be said that the manufacture had stood still.

Reynolds. Mr. Edward Reynolds said that many persons besides the Author had arrived at what he thought was the erroneous conclusion, that because test-pieces often showed very little difference of result after annealing, therefore the annealing had produced no effect. When, about six or seven years ago, his company started a plate-mill, the first plates made were 50 feet long, 3 feet 6 inches wide, and $\frac{3}{4}$ inch thick, to be split into two plates for girders. He watched them, and saw that the cooling was what would be generally considered approximately equal. Of course the edges were cooled to some extent first; but he fully expected that the removal as usual by the shears of 3 or 4 inches from each edge would have cut away the part which had apparently cooled first. But when the plates were split by the shears, there was still so much tension

left from the edges having cooled first, and the centre having tried to contract afterwards, that it was only possible to split by the shears about 20 feet from each end, because the contraction of the centre caused the divided ends to cross over each other so much that the centre of the length had to be divided by other means. That kind of tension must exist in every large piece of material that had been cooled from the outside. If a test-piece had been taken from the centre of the plate afterwards, it could not have been tested in the same condition in which it had existed in the plate under tension; because it would have had a chance of relieving itself from the tension. A similar action was very observable in more important matters, such as in cutting out the centre piece of large crank-shafts. In this case, also, test-pieces did not in the least indicate what internal strains might have existed in the mass. It was therefore important to anneal the whole piece for the sake of relieving this internal tension. With regard to the Author's experiments on compression, he did not understand what they meant, but as he understood he merely squeezed the specimen sideways and then tested it endwise. But that was not the way in which compression occurred in a boiler-plate. In the discussion on a Paper that had been read before the Institution, Mr. Parker of Lloyd's had referred to some plates which had failed.[1] They were 20 feet long, $1\frac{1}{4}$ inch thick, and were intended for the semi-circumference of a large boiler. Now the difference in the semi-circumference with a plate $1\frac{1}{4}$ inch thick would be nearly 4 inches, of which about one-half, or perhaps more, would be taken up by compressing the inside part in the direction opposite to that in which its working-strain would come, the outside being stretched to that extent. He believed there was no knowledge at present as to how far a material artificially compressed when cold, as by being bent in rolls, was in a state to take its fair share of tensile-strength. That was a point well worth investigation. He hoped himself to try it by comparing pieces of axles, both in their natural state and after being compressed endwise by the hydraulic press. That was the only sense in which he thought the question of compression of boiler-plates could be considered. Mr. Reynolds.

Mr. R. A. Hadfield remarked that although he had not had much experience on the question under discussion, he believed that the effect of annealing upon forged steel was very beneficial; most certainly this was the case upon steel in its cast state. A piece of the latter, which had a tensile-strength of 30 or 32 tons in Mr. Hadfield.

[1] Minutes of Proceedings Inst. C.E. vol. lxxxiv. p. 148.

Mr. Hadfield. its raw unannealed state, would possess only 8 or 10 per cent. elongation; but by judicious annealing the elongation could be readily increased to 25 or 30 per cent. on 2 inches. As to the Author's advocacy of making steel with increased tensile-strength, he thought this might be safely done. Large quantities of steel for axles produced by his firm had a tensile-strength of 36 to 40 tons per square inch. Hundreds of thousands of such axles had been made, and, practically speaking, without any failures; and naturally the durability with this harder temper was much greater. If, therefore, advantage was to be gained by using steel of increased strength, it could without doubt be made. He had recently tested some steel, the tensile-strength of which was close upon 40 tons per square inch, with 25 per cent. elongation, and nearly 50 per cent. reduction of area, the elastic limit being about 23 tons. If such steel were brought into use, no doubt constructive machinery in general could be considerably lightened, and such lightness could be obtained with equal safety to the present.

Mr. Stirling. Mr. James Stirling drew attention to some sections of steel boiler-plates which he had brought for exhibition. The samples were from plates supplied by five different manufacturers. After carefully comparing steel with best Yorkshire iron, he had derived great satisfaction in using the former for the manufacture of boilers. With regard to annealing, it was perhaps of great importance in some cases, but he did not consider it essential in boiler-making; he had not the necessary furnaces for annealing plates, nor had he the required apparatus for drilling; he therefore followed the old fashion of punching, and until he could get the makers to satisfy him that they could supply plates which would stand the same treatment in working as best Yorkshire plates, he should not feel justified in building locomotive boilers of steel. Some years ago he applied to a number of the principal makers, and obtained samples of their steel plates, which he treated by shearing the plates 3 inches broad, punching them, planing them upon the sides to $2\frac{1}{2}$ inches broad and equidistant from the centre of the holes, then drifting them by six drifts $3\frac{1}{2}$ inches long. These drifts were driven through the plates by a weight of 50 lbs. falling 6 feet. The drifts had a taper of 1 in 28, and the holes were drifted from $\frac{13}{16}$ to $1\frac{1}{2}$ inch. Having satisfied himself that plates which would stand such a test must be good material, he felt sure that he was going in the right direction in adopting steel plates for boiler-making instead of best Yorkshire iron which he had previously used. He had tested best Yorkshire iron in

the same manner, and the results were not at all satisfactory; it would not stand the drifting-test. He had not found any disagreeable symptoms in the employment of steel plates which would induce him to return to the use of iron. Mr. Stirling.

Mr. W. Stroudley said that the Author had drawn attention to a convenient method of testing a plate, which might perhaps be already cut down to size, so that there might be certainty as to the quality of the material. The testing of steel was, he thought, the only means of securing the uniformity which he believed to be necessary where a number of pieces were brought together to make a structure of any kind, particularly a steam-boiler or the hull of a steamboat. Ten or eleven years ago he recommended the London, Brighton and South Coast Railway Company to adopt steel for building some steamers, both for the hulls and boilers, and his suggestion was adopted. He was told to take extraordinary care, and he had a test taken from every plate used, and found that it was quite possible to obtain plates that only varied 2 tons in tensile-strength per square inch; in fact, the bulk of the plates used in the boilers were within 30 cwt. in the breaking-strain. It was of the utmost importance, where plates were drawn together, that they should have a uniform elasticity, so that the whole strain or value of the steel could be brought to bear, and not to have the plates stressed or damaged in detail. He had taken great pains in obtaining that result. In some boats now building boilers were being introduced with one plate forming the under side of the boiler above the water-line. Some day he hoped to get them made of one plate quite round without a joint. The plate exhibited in the Manchester Exhibition, by Sir Joseph Whitworth's firm, was such a plate for a marine boiler, being a solid ring about 12 feet in diameter and $\frac{3}{4}$ inch thick without joint. When steel-makers would turn their attention to rolling such ring plates 14 or 15 feet in diameter, boiler-making would be a much better work than at present. Sufficient stress could not, in his opinion, be laid on the necessity of keeping steel of one uniform strength when used for the same structure. Mr. Stroudley

Mr. E. A. Cowper remarked that there were other metals besides steel which, if melted and cast properly, would also bear great strains. He had brought for exhibition a few rings of the "Mitis" metal, that was being cast by Mr. Nordenfeldt. They were of wrought-iron, melted and cast. There were a few washers which had been drilled and drifted to about the same size as that of the mild steel washers described in the Paper. The excellent result, he believed, was owing to the metal being homogeneous and very Mr. Cowper.

Mr. Cowper. soft, having very little of carbon. The quality was also shown in other samples; for example, a spanner that could be twisted two or three times round, or bent backwards and forwards, without giving way, because the metal was so homogeneous and soft.

Mr. Stanger. Mr. W. H. STANGER inquired what was meant in Tables IX and X by "elasticity began." Elasticity was an inherent property of a metal, hence it was absurd to speak of its beginning at a certain stress. Of course there was a point where a metal lost its elasticity, namely, when the elastic limit was reached, and the metal took a permanent set. Extension began the moment stress, however small, was put upon the metal. He thought the Author had spent an enormous amount of labour upon experiments of very little value; his method of testing appeared to be retrogressive rather than progressive; for the tendency of engineers at the present time was surely towards the use of large rather than of small test-pieces. The power of testing-machines was increasing; a 50-ton machine was considered small, 100-ton machines were not uncommon, and they had been made up to 400-tons capacity. Notwithstanding this, the proposal was that material should be tested by means of buttons with holes through them; he could not think that such a method was an advance. He would rather advocate a testing-machine capable of testing whole plates (of course not going beyond the elastic limit), and he hoped some day that would be accomplished. By the process under discussion, it was impossible to obtain any history of what the piece of metal was undergoing while being tested. By means, however, of an autographic stress-strain apparatus, such as Wicksteed's, this could be accomplished from the moment the smallest stress was put upon it to the time when it broke under the load. The only result shown by the Author's method was a certain amount of elongation, and that elongation was measured from what was called a "neutral circle." He thought the position of the neutral circle had been rather assumed than proved. He was afraid the deduction was not a very safe one; and he did not think it fair to institute a comparison with the extension upon a tensile specimen. The Author appeared to have taken the measure of the circumference of the neutral circle and compared it with the datum points on an 8-inch tensile specimen; but he ought to have taken it between points on the tensile specimen at the point of fracture, and not over the whole length of the specimen. He directed attention to a few diagrams of the autographic stress-strain apparatus on the table, which he thought were of some interest.

Mr. Bruce. Mr. G. B. BRUCE, President, understood the Author to have

proposed his method for the testing of a plate which had been already cut to size, out of which he could not cut a test-piece in the ordinary way. He punched one of the rivet-holes, drilled a small hole in the piece, and then elongated it by drifting. Mr. Bruce.

Mr. W. B. Lewis said a few years ago the Government of Victoria let to some Belgian makers a contract for steel tires and axles. The tires were to be made of very strong steel that would stand a tensile-strain of 45 tons per square inch, with an elongation of not less than 20 per cent. in a test-piece 5 inches long. English makers refused the contract, and it went to Belgium. He was requested to send over an inspector, and he went over there once himself. After some trouble the manufacturers succeeded in producing this steel with great regularity. The first nineteen tests, after regular working had begun, showed an average of 47·75 tons breaking-strain, and 21·54 per cent. elongation. The English manufacturers were not willing to be outstripped. One of the best of them visited Melbourne and managed to get a reduction from 20 per cent. elongation to 15 per cent., and he obtained a contract for similar tires. The first set of tests brought to him were, if he remembered correctly, about 43 tons, which was below the specified breaking-strain, but they were so regular, that he had no hesitation in saying that they were more satisfactory than a higher but irregular result would have been. Another large manufacturing firm in England determined to try, and after a little trouble produced an uncommonly good result. The Belgians did not anneal except in two or three cases where there were failures, when they asked to be allowed to anneal, which sometimes brought the metal up to the test. The older firm of the highest reputation for this class of work made steel tires without annealing, but the new people annealed everything, and the older ones were now following their example. All the firms to which he had alluded were now supplying material well up to the specified tests. Mr. Lewis.

Mr. Druitt Halpin stated that he was no friend of punching, but it should be remembered that if holes were punched and subsequently riveted, nature tried to help with a sort of compensatory action; that was, the rivet-holes were partially annealed by the presence of the rivets themselves. Mr. Halpin.

Mr. J. D. Ellis asked what the Author meant by the tempered bending-test? whether he meant a quenched bend, the steel being heated, and thrown into the water and then bent. Mr. Ellis.

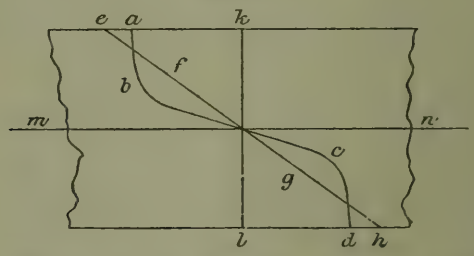
Mr. B. Baker said that Mr. Reynolds had raised the question whether the previous compression on steel affected its strength. Mr. Baker.

Mr. Baker. It did not affect its tensile-strength, but it considerably lowered the limit of elasticity. Nothing showed the influence of previous strains on steel better than experiments on long columns. A few years ago he investigated this question, and arrived at some interesting practical results. The resistance to flexure of a solid mild steel column 30 diameters in length varied according to previous treatment as followed:—

	Tons per square inch.
Annealed	= 14·5
Previously stretched 10 per cent. . . .	= 12·6
„ compressed 8 „ . . .	= 22·1
„ „ 9 „ . . .	= 28·9
Straightened cold	= 11·8

These results were very suggestive in many respects which he could not then refer to. Mr. Reynolds had also noticed the condition of a boiler-plate which was bent cold. It had always been

Fig. 9.



a matter of surprise to him how any one could imagine that a boiler-plate bent cold and not subsequently annealed could have a uniform tension on it under steam-pressure. This could be proved theoretically. If k, l (Fig. 9) represented the thickness of a plate bent cold beyond the elastic limit, the reactions of the different fibres would be indicated by the curved line a, b, c, d, because a sudden change of length occurred at the yielding point or elastic limit. If the reactions had been represented by the straight line e, f, g, h, no initial stresses would have remained in the plate; but being as they were there would be permanent initial tensile and compressive-stresses e, a, and d, h, at the skin, and b, f, and g, c, in the interior of the plate. In order to test the matter experimentally he bent plates, and planed off the outside skin to a certain depth, leaving the interior couple unbalanced. The immediate result was that the radius of the plate altered. The intensity of the stresses was pretty heavy—about 7 tons per square inch on the outside skin and 12 tons near the centre. Those

stresses, varying in intensity according to the amount of bending, undoubtedly remained in the plate if it was not subsequently annealed. He had very recently made another test with a steel bar 11 inches wide. The bars were not delivered straight, and it was necessary to straighten them by bending edgeways. They were bent with sheared edges, and it was not surprising that many of them broke if not annealed. He wanted to see what initial stresses were left in by straightening them. In order to do that, having straightened a bar, he planed the edges so as to get straight lines, and he then sawed the 12-foot long bar longitudinally through the centre. The condition of the stresses was, as shown by Fig. 9, *k*, *l* representing the width of the bar, or 11 inches. By cutting it down the centre *m*, *n*, he left the forces *e*, *a*, and *b*, *f*, to act. Directly he sawed the bar through it became curved to the calculated theoretical amount, proving that the stresses induced in the bending were left in the bar. With regard to annealing, although it was advisable for plates which had been severely worked for boiler or other purposes, he thought it would be a mistake to assume that plates should be annealed for ordinary girder-work. He had used nearly one hundred thousand steel plates, and he had never had a failure from not annealing in such cases, if they had been made by a good maker. Now-a-days there was not much difficulty in getting a good maker; the difficulty was to find a bad one in this country. It was not his experience that the effect of punching was relieved by the annealing effect of hot rivets. He had not found from the results of tests of riveted joints that a rivet did anneal in any trustworthy respect whatever.[1] The heat of a rivet did not go very far. He had tried the matter several times. He drilled some small holes in a plate near the edge of a rivet-hole and put in lead, and the heat of the rivet was not enough to melt the lead. He also put in water, and it was not enough to evaporate the water. One point about sheared edges ought to be noticed, because it explained somewhat the conflicting results obtained in bending

Mr. Baker.

[1] The following more recent experiments of Mr. Baker's confirmed this conclusion. The specimens were cut from a ¾-inch thick steel plate, and the rivets were ⅞ inch.

	Ultimate Stress per square inch.	Extension in 8 inches.
Ordinary test-piece	32·66 tons	22·0 per cent.
Punched hole, machine riveted . .	30·18 „	3·1 „
„ „ hand „ . .	30·64 „	2·2 „
„ „ annealed	35·37 „	6·2 „
Drilled hole, machine riveted . . .	35·13 „	5·5 „
„ „ hand „ . . .	34·47 „	6·2 „

Mr. Baker. specimens cold. Taking the case of an ordinary specimen 2 inches wide with sheared edges, and bent cold without previous annealing, in nine cases out of ten it would snap like a piece of cast-iron. Occasionally it did not so snap, and that might lead to the supposition that the shearing did not always produce the effect indicated by general experience. The explanation was that the bar was bent in a different way. The upper edge of a sheared plate was rounded, and the lower edge was jagged and torn. If the specimen were bent so that the rounded edge was in tension it would not break like cast-iron, which happened when the jagged edge was in tension. Mr. Stroudley attached importance to getting plates within a limit of 2 tons variance in tensile-strength to the square inch. There was not the slightest difficulty in that, because the tester, by delaying the test a little or hurrying it on, could get a considerable variance in the result. In gauging a test-piece, too, the same thing occurred, and he had no doubt that if it was wanted within $\frac{1}{2}$ ton the tester could arrange it. When he tested his own specimens he did not find such uniformity, and it did not matter in the least. He could not imagine any theoretical reason why a piece of 28-ton steel should not work perfectly well with a piece of 38-ton steel if necessary. They both had the same modulus of elasticity. The only difference was in the ultimate strength, which did not much affect the matter, because they did not work anywhere near it. To ask the manufacturer to limit the variation to 2 tons instead of 3 tons would be an inconvenience to him; the buyers would have to pay for it, and it would be no advantage when done. He had said that in regard to plates which had not been bent he did not trouble about annealing. In America, where steel eye-bars or bridge-links were made by heating the ends of flat bars and forming the eye, it was the practice to anneal, because if they were not annealed they broke without the proper elongation. When in America on one occasion he had some steel, which had been made in Scotland under his inspection, tried without annealing. The American firm who made the eye-bars thought they would fail in the specified elongation. The firm usually annealed the bars by putting them in a great bonfire of shavings of wood, and giving them half a dozen hours to cool in the ashes. He asked the makers to rub one of the bars over with ashes so that it might look as if it had been annealed, and to send it to the testing-works. That was done, and it stood the same test as the others. The makers thought it was a somewhat remarkable piece of steel, but the result accorded with all his previous experience.

Steel rivets got heavily punished and could not be subsequently annealed. How little they suffered was proved by the trouble of cutting them out. It had been said that it was not necessary to anneal iron. It so happened that the links of the old Hammersmith Bridge had been acquired for temporary use in the Forth Bridge, and about 1 per cent. of them broke in the carriage, and two of them broke in work. That had not happened with a single steel plate or bar that he had had to deal with. The result was that he had not considered it safe to use those wrought-iron bars without previous annealing, and every one was annealed. He had before him the results of the tests on the steel eye-bar above referred to, 8 inches by 2 inches in cross section, and found the elongation was 20·76 per cent. over a length of 8 feet, and 37·5 per cent. in one 12-inch length. The total stretch was upwards of 2 feet, which could not have been approached by any similar iron bar. Mr Baker.

Mr. J. N. Paxman observed that the Author's method seemed an ingenious one for ascertaining the exact nature of the material in the particular place where a fault occurred, and it opened up new ideas. Of course the method in question was not supposed to be very accurate, nor to give all the data of a very refined test, but he thought it was a sufficient guide. His own experience of open-hearth steel was favourable. He had employed it for many years, and had had nearly thirty thousand steel plates. During the last twelve months he had used two thousand four hundred and nineteen plates without a single failure. Steel of this nature was obtained from most of the best makers. With reference to a front boiler-plate which he exhibited, he stated that it had been stamped out and levelled in one heat. But it required, so to speak, two operations. The internal flange was the one that was first operated upon. While that was being done a little time was lost, and cooling took place; there was, however, sufficient heat left to finish the outer flange and level the plate. That was an accomplishment which he believed all engineers were aiming at, because plates deteriorated somewhat in proportion to the number of heats to which they were subjected, and therefore it was the desire of engineers to perform as much work as possible in one heat. The combustion chamber was of a peculiar kind, being pressed out in two heats, and that perhaps was as severe a test as steel could be put to. It was pressed out 8 or 9 inches at right-angles, without any inconvenient reduction of thickness. The first heat turned up the ends a little, and in the second heat these edges impinged on the die and the metal was pressed down in such a manner as to prevent the thinning of the plate. The Mr. Paxman.

r. Paxman. die was then lifted for a second, and a few blows were struck with a mallet to bring the edge of the plate slightly over, and the die was replaced and the plate pressed into proper shape, with flanges, &c. A material which would stand as that had stood without a fault, in a great number of plates, must necessarily be of excellent quality. According to his experience, steel was far preferable to the very best Yorkshire iron. With the exception of those made of copper, his firm had for many years made locomotive-boiler fireboxes entirely of steel, and had found that their life was considerably increased, and the repairs were much less. A large battery of these boilers had been in work for years at the Exhibitions at South Kensington without a fault of any kind. The boilers had done work for six months at a time, and not one of them had given way. If the same number of boilers provided with iron fireboxes had been worked and pressed as hardly as these had been, some of the plates would certainly have given way. Steel, he thought, was a much better and safer material, and would eventually supplant iron for boiler construction.

Stromeyer. Mr. C. E. STROMEYER said some years ago he had carried out experiments on steel, with regard to the question of blue-heat.[1] He was glad to hear this Paper read, as it was another attempt to solve the difficult questions attending the use of mild steel, and he could fully appreciate the great trouble which the Author had taken in conducting his experiments. He was only sorry that the behaviour of the various specimens had not been described more in detail. For instance, it would have added to the value of the Paper if a note had been placed against each experiment, showing how much thicker the specimen was on one side than on the other after it had been stretched. It would also have been interesting to know whether the specimens had been thoroughly gauged after they were turned. He should think that the least irregularity in the thickness of the sides would make a difference in the amount of elongation. Most probably the thin part would give way first, and the amount of stretch in the test-ring would be less if the hole were eccentric than if it were absolutely in the centre of the piece. He had noticed two or three strange results: one of the test-pieces had cracked half through one end long before it did through the other. Another piece did not stretch at all on one side, but very much on the other. He wished to ask whether the test-pieces were punched out of the plate or trepanned out of it, because that would make

[1] Minutes of Proceedings Inst. C.E. vol. lxxxiv. p. 114.

an important difference. If they had only been punched out, he thought the value of the experiments would be comparatively small, and if they had been trepanned, and all the other precautions taken, the experiments though valuable, only pointed out that this test did not give as reliable results as might have been expected; for the difference in the behaviour of test-pieces cut from good and from cracked plates was certainly not sufficiently marked to be a sure guide to their condition, especially as the tests of good plates showed large irregularities. Mr. Stromeyer.

Mr. JOHN GOODMAN, in reference to some remarks that the Author's method was not a fair way of testing the quality of steel, believed that in the carrying out of his experiments Mr. Goodall intended his method to be a supplement to the ordinary tests, rather than a substitute. He had dwelt in several places on the elongation of the specimen, and he had given the calculated elongation on the washers to compare with the elongation on an 8-inch specimen. It would be found from the last two columns of the Tables (p. 7) that the whole of the calculated values amounted to exactly 45 per cent. of those of the actual elongation on the neutral circle. He thought it was not an accurate way of measuring the extension to take the neutral circle as the central circle between the outer and the inner diameters. It would be far more accurate to take a circle at the mean thickness of the plate. The inner part of the specimen was, of course, thickened by compression, and the outer part was thinned by tension. The question of annealing had been referred to, and the results were very discordant. The Author had come to the conclusion that annealing did not improve steel plates. He should be very much surprised to find that those tiny buttons had shown any difference whatever. Annealing was nothing more nor less than bringing the plate to a state of homogeneity. Through unequal heating, in the manufacture or afterwards, one part of the plate was left in tension and the other part in compression, and then when it was heated the tensions and compressions were nullified. If a button were cut out from one part of the plate which was originally in tension, the tension would be released, and the specimen would be brought back to its original state. It would be exactly equivalent to cutting one of the buttons from a test-specimen when in the testing-machine under a given stress, and of course when the button was cut out the stress would disappear immediately. The Author had also said that annealing was not necessary with iron plates, and he had asked why it should be necessary with steel plates. The answer, he thought, was very clear. It had for a long Mr. Goodman.

Mr. Goodman. time been known that the coefficient of heat-expansion increased with the percentage of carbon. With a wrought-iron plate a very small percentage of carbon was present, while with a steel plate there was a much larger percentage. If, therefore, it was locally heated, the extensions or compressions of a steel plate were much greater than they would be in the case of an iron plate; consequently the internal stresses were much greater in the steel than they would be in the iron plate. Reference had also been made to the elongation, which was a very important matter in connection with the extension of test-pieces. If a test-piece 2 inches long were taken, and another 10 inches of the same material, on the total length a much larger extension would be got on the 2 inches than on the 10 inches, simply because the test-specimen remained parallel for a great part of the test, and then suddenly drew down locally. That local extension was much greater than the parallel extension, if such a term might be used; consequently in the small specimens there would be a much greater extension than on the 8-inch length. If the extension were specified as being apart from the local extension at fracture, a comparative result would be obtained whatever might be the length of the test-specimen. Of course that amount of extension could only be obtained when an autographic stress-strain diagram was taken, or at least not without a great deal of extra trouble. When the stress-strain diagram was drawn, it was obtained without any trouble with a single measurement, from the point where the curve began to go back at the time of stricture. It would have very much added to the value of the Paper if the reduction of area had been given as well as the elongation of the test-specimen. It would then have been an easy matter to calculate the extension in the stricture from the reduction in area. He considered that a bending-test was, for rough purposes, better than a drifting-test. In the first place, the exact amount of extension could be easily measured; the stress that produced that extension and fracture could also be easily calculated within a very small percentage of the breaking-load. He had recently calculated out some beams in that way, not by the ordinary formula, but by an improved method, and had found that they came within 1 or 2 per cent. It appeared to him that the test-specimens shown were similar to a gun-rim: they had a tremendous compression in the inside, and a large extension on the outside. Mr. Stromeyer had spoken of the specimens being smaller in one part than in the other, possibly because the hole had not been drilled exactly in the centre. Mr. Goodman thought it was nothing more nor less than the equivalent stricture found in ordinary parallel test-specimens. Mr. Baker, in speaking of the breaking-loads of

various steels, had stated that it was an easy matter to get ½-ton error. He was probably speaking of the manufacturer's tests, not of those carried on in a proper testing-house, where the specimens were measured to within $\frac{1}{1.000}$ inch, and most of the testing machines would record at least $\frac{1}{100}$ ton. When due care was taken there was no possibility of getting such a large error as ½ ton per square inch. Mr. Goodman.

Mr. JOHN I. THORNYCROFT said that his experience was not great in connection with the kind of plates which were particularly under discussion. Such plates seemed to fail in a manner which was very rare in the thin plates he had generally to deal with. The steel which led to the greatest danger, from its uncertainty, was stated in the Paper to be that of plates which bore a considerable thickness in proportion to that of the ingot from which they were made, and no doubt that was so; but this was not the cause of the failure. It might be more correctly attributed to the long period required for so large a mass of metal to set in the mould. Much had been lately heard about the separation which was liable to take place in alloys of steel. The separation partly depended on the time of cooling of the ingot, and therefore as the size of the ingot increased time was given for the various alloys to separate themselves more completely. That would lead to the supposition that if means could be devised for more rapidly cooling the ingots, some advantage might be gained, or if, as Sir Joseph Whitworth had done, steel makers could compress it and use an annular casting, the centre of the ingot would be cooled, and the time of cooling would be lessened. He believed also experiments had been made which proved that pressure forcing the atoms together not only lessened the volume of the gas contained in the ingot, but caused the liquid portion to set at a higher temperature than it would otherwise do, and thus helped to prevent the separation of the alloy into its component parts. His own experience had been in connection especially with thin plates, where the amount of rolling had been great; and perhaps as a natural consequence the steel had behaved so well that it had given him very little anxiety. There was only one metal which he had seen worked that was more malleable, namely, copper, electro-deposited. It was deposited on a mandrel, and afterwards rolled, and homogeneous pipes were made from it, from which electric cables of pure copper could be manufactured. With regard to testing the pieces referred to, he estimated the Paper as very valuable, because it enabled the plates to be tested locally. The Author was right in his statement that in various parts of large Mr. Thornycroft.

Mr. Thornycroft.

plates there was a different composition of metal, and a different strength. The separation of which he had spoken of the several parts came into play, and the result was weak alloys and strong alloys, or rather unreliable metals, all in the same plate. Any imperfection was aggravated by local heating, and perhaps, as had been argued, in that particular form of testing the effect of annealing was to a certain extent immaterial when so small a piece was tested; but surely this also applied to the ordinary test-piece about 2 inches wide, which, when cut from a plate, would alter its form and eliminate the unequal stress in the same way to a great extent. The Author had compared the elongation of the rings with an ordinary test-piece; but there was one point which he thought had not been considered. Taking a ring of considerable thickness compared with the hole in it, there was a kind of stability in the different parts of the ring to help one another, so that one side could not be broken without deforming the other, and if one side showed signs of stricture the other part helped it. From that cause alone greater parallel elongation was undoubtedly obtained than from an ordinary test-piece. But there was another circumstance which tended to balance that; the material immediately round the mandrel was comparatively much more extended than in the other case, for the elongation of the inner surface was very great as compared with the outer. In attempting to ascertain the strength of specimens in that way, it appeared to him that the uncertainty of the coefficient of friction of the mandrel was an unfortunate element, and he was surprised that it did not appear to give a greater source of error than that stated in the Paper.

Mr. Beaumont.

Mr. W. W. Beaumont observed that there were two or three points in connection with the methods of testing proposed by the Author, which had not been referred to, but which were of some importance in estimating their value. The Author had stated that "it is evident that in drifting a washer, the inside is in compression and the outside in tension; efforts were therefore first made to find the neutral circle." Mr. Beaumont thought that a great deal of difficulty would be experienced in finding that neutral circle, considering that the whole ring was extended, and in showing that the inside part of the washer was compressed to any measurable degree, or to such a degree as to have any effect on the extension of the material. There was of course no such neutral circle. It was well known that materials might be caused to extend to a greater degree if pressures were brought to bear at right-angles to the direction in which the main test was being

made. Thus, if a piece of material while under tensile-stress, as in a testing machine, were also under simultaneous orthogonal pressures, extensions were more readily made; and although it could not be said that the washers were under such pressure, there was a pressure from within which possibly tended to help towards an unusual extension of the ring as a test-piece. Not long ago Colonel Maitland had shown to the Institution,[1] by experiment, that when a test-piece was subjected quickly to a stress calculated to extend it in length, as by drop-tests or by gunpowder, the amount of extension was very much greater than when the tests were slowly applied. If such were the case with all kinds of materials of that character, it would seem that a drift driven into a washer was a tool for suddenly applying such pressures, and it might therefore be expected that the extension would be greater, as the Author had shown in his tests. He therefore thought that as far as the tests were concerned, with reference to the strength of materials, if the results were to be compared with other experiments, the Author's method was not of very general application, although it might provide a rough test for minimum strength, from which boiler constructors could satisfy themselves as to the character of a material as compared with similar material tested in the same way. Moreover, the test-pieces were so small, that any stress that might be resident in the material itself, might be said to be eliminated; in other words, the number of particles might be said to be so small that the contending influences were also small, and what were commonly called differential molecular stresses were really almost absent, the material being cut up into such small pieces. For that reason, also, he thought it questionable whether the Author's method had any very wide application. The same thing held good with regard to the value of the Author's remarks concerning annealing. No very great difference of behaviour would be expected between very small pieces like the washers from a plate annealed and that of similar pieces from a plate unannealed. With regard to the large plates exhibited, he should be glad to know whether the manufacturer found it necessary to anneal them after they had been pressed, before they were put into the boilers; and secondly, whether the combustion pieces had been known to crack after they had been riveted up in the boilers. The pressing was of a very complicated nature, and if mild steel would fly after being pressed into shape, that was certainly a case in which it would do so.

Mr. Beaumont.

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[1] Minutes of Proceedings Inst. C.E. vol. lxxxix. p. 120.

Mr. Paxman. Mr. J. N. PAXMAN said it was the custom in his establishment to anneal all plates after they had been operated upon in the furnaces. The plates exhibited had both been annealed. It had been found from practice that annealing was absolutely necessary. Local strains were set up by partial heating, and they were rectified by proper annealing. It was true that the tensile-strain was sometimes reduced a little; but he liked to have the strain under 27 tons per square inch, because then the metal seemed tougher and more suitable for fireboxes. With reference to the large plates, it had been found that, in manufacturing, they had not given out, and that they were round at the angles. No difficulty had been found in welding the steel plates. His firm had for many years used this steel, and welded the flues of Cornish, Lancashire, and other similar boilers. But experience showed that at the part welded it would not bear so heavy a tensile-strain, neither was the elongation so great, the reduction having been from 7·55 to 13 per cent., these being the minimum and maximum so far as shown by tests.

Mr. Goodwin. Mr. GEORGE A. GOODWIN observed, with reference to the remark by Mr. Thornycroft, on some very malleable electro-deposited copper tubes, that he no doubt referred to some tubes Mr. Goodwin had had to do with a short time back. Some clients of his were shown patents for making these articles, and undertook to purchase them, provided the representations made with reference thereto were true, namely, that the copper would stand 32 tons per square inch, and elongate 38 per cent. Finding, on inquiry, that this was not the case, his clients refused to purchase the patents, and the patentee sued them for £15,000 damages. He was then engaged as engineering adviser to investigate the matter, and he found that the copper only stood 15·2 tons, with an elongation of 38·3 per cent., the fact being that the 32 tons was the strain on the fractured area, consequently the action was dismissed.

Mr. Hodge. Mr. W. R. HODGE said that the Author's experiments were not so exact as could be desired, but he thought they gave very fair results. Trustworthy and successful results could only be obtained by the expenditure of a great deal more time and money. As a material for boiler-making, he regarded steel as incomparably better than any iron. In the use of Siemens steel for many years some of the contingencies referred to by the Author had certainly taken place; but since the open-hearth system had been introduced, exceedingly few plates by reputable makers had failed. During the last five years he had only known two cases of failure after the metal had been manipulated and worked. In one case

the cause could not be traced, and the steel had come from a firm of the highest reputation. In the other case the steel was not produced by makers of such high reputation, but it behaved in a similar manner. A flanged end of a boiler about 7 feet in diameter was being put into the shell, and on a slight blow being given to force it in, it split to the extent of 6 or 8 inches. He thought there was very little difference between the makers. The Steel Company of Scotland and the Landore Company no doubt produced steel of a very high character. There was also a firm near the Steel Company of Scotland that stood equally high; and that firm turned out steel that could be easily and successfully welded. The other steels did weld, but in nine cases out of ten he thought they were not of good workmanship. After the weld had been effected, certain little incipient cracks started up in the cooling. They seemed to be almost confined to the surface, but they did exist, and a good workman would say that the weld was not a perfect one. That appeared to him to be the only objection to the use of steel for boiler-making. He believed that steel of low tensile-strength was better for boiler-making than that of a higher tensile-strain; it was much softer, but for boiler-making and for welding purposes it was much more reliable. Another great advantage of steel was the absence of lamination. In all his experience he had only known one plate rejected for lamination. In the old days of superior iron for marine boilers the plates often developed lamination, and at the last moment had to be rejected, and sometimes for a second and even a third time. He believed that in ten years no plate in his works had been rejected from that cause. The manufacture of steel had been so greatly improved that it was now far superior to any iron.

Mr. Hodge.

Mr. Daniel Adamson regretted that the Author was not living, that he might have been complimented upon the pains he had taken in the experiments recorded in the Paper. The value to be placed upon his experiments was another matter. Mr. Adamson had listened with considerable interest to the discussion on the superiority of steel to iron, but he had failed to gather anything which would enable engineers to select a steel suitable for the purpose for which it was intended. The Author's experience of steel for boiler-making commenced in 1875, and he had used upwards of four thousand plates. Mr. Adamson's experience was not so limited, he having used, between 1860 and 1875, a much larger number of plates. The Author had stated that punching was common at the time when open-hearth steel was adopted, in 1875, but Mr. Adamson had not punched a boiler for years before

Mr. Adamson.

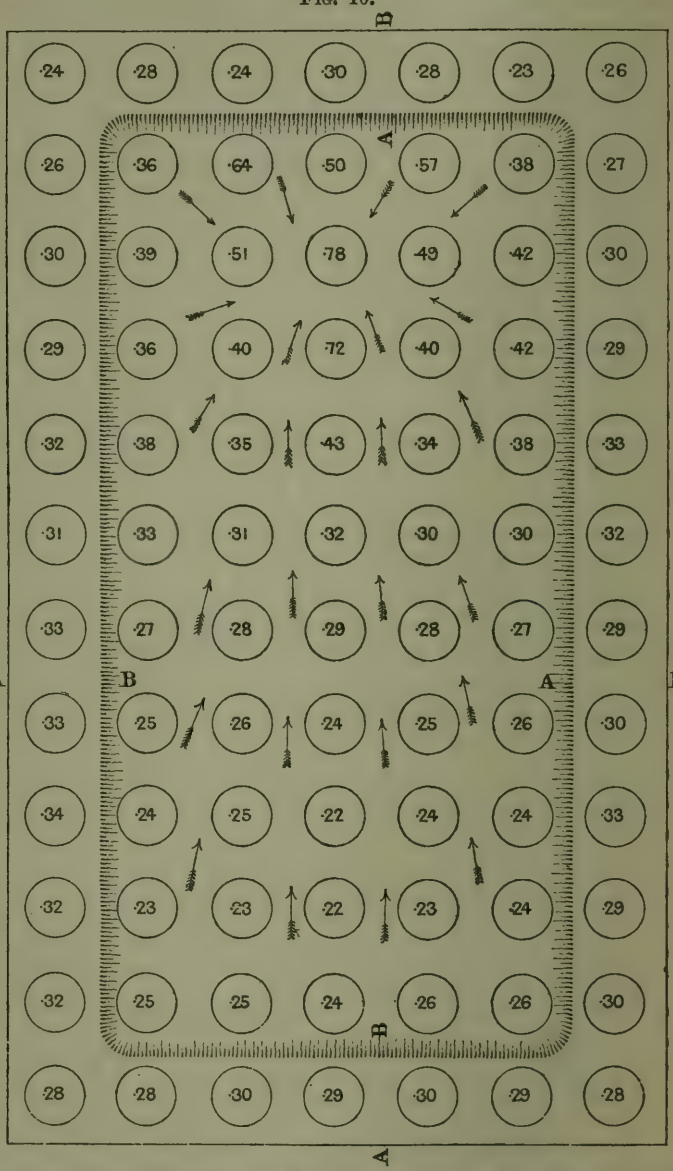
r. Adamson. that time. His first patented arrangements for drilling shell-plates in position were dated 1862. He soon discovered that it was nearly as cheap to drill plates as to punch them; but, before that, he had satisfied himself that all punched boilers were inadmissible, especially when made of steel, and that punching was a barbarous practice, and never ought to be used where uniformity of strength and great trustworthiness were required in a structure. He was led to that view first by the drilling of angle-irons, which he found did not warp nor become distorted, and it was not necessary to re-heat them for stretching and levelling, and therefore there was no cooling over limited sectional areas, so that destruction did not arise through contraction when the metal was passing over colour heat. He then adopted drilling as a universal system, but he was not supported, and he did not receive 6*d.* royalty during the life of the patent. It was evident to him that the Author had not been a steel manufacturer; and he certainly was not a metallurgist, and he had not a large experience as a steel-boiler manufacturer. To be guided by sound experience, and a knowledge of the fundamental law of the strength of iron and steel, all the properties of pure iron itself must first be understood; iron so pure as, when chemically examined, to be represented by Fe 99·98 per cent. If pure iron was wanted for strength, endurance, and even weldability (he had had some in his hands which he thought would cost £100 sterling per ton), it was a very ductile material, but it would not carry more than 19 tons per square inch, and it would certainly take a permanent set as low as about 9 tons. Such a pure material certainly would not be found to possess great tensile-strength, yet it had a power of endurance beyond any steel as regarded stretching and elongation under stress, indicative of great malleability and ductility. In it there was something like a foundation upon which manufacturers could rest their judgment as to alloying up to the necessary extent, and in selecting a material that possessed ductility to meet all requirements, that would endure working over a large range of temperature, that would carry half as much load again as ordinary good iron, and which would therefore be desirable both in regard to cost and weight. While it possessed about equal strength in a longitudinal and in a transverse direction, pure iron would, no doubt, stretch, in a length of 10 inches, about 40 per cent. up to its maximum carrying power of 19 tons per square inch; but it would take permanent set at a strain not exceeding 9½ tons per square inch, and it would ultimately break down under the same force, but the elongation would have gone up to 55 per cent. under local exten-

sion. He might state, with respect to diminished sectional area at the point of rupture, that all sections of a ductile metal broke over a local elongation of about four areas. In the case, therefore, of a short specimen 2 inches in length, such as was formerly used as a test-piece at Woolwich, there was an enormous extension, when there might be only a comparatively poor material, because all local elongation was developed over that short length. If steel was wanted so far alloyed as to carry from 29 to 30 tons per square inch, which was very practicable and very dependable, in order to get it to be a good working metal there should not be more than 0·15 per cent. of carbon; there might be as much as 0·45 per cent. of manganese, and, as far as the other alloys, silicon, sulphur, and phosphorus, were concerned, their combined quantity should not exceed, for ordinary purposes, 0·15 per cent. But if the material was wanted for welding purposes, the sulphur should be a much lower proportion than 0·05 per cent., which seemed to be indicated in the statement that the three compounds might give a total quantity of 0·15 per cent. He had used open-hearth steel in 1861, and a specimen of it might be seen in the Wolsingham Steelworks. It was a boiler he made for Mr. Attwood, of Towlaw, who was an open-hearth steel maker, a metallurgist, and a superior commercial man. He believed it was working at the present day, and carrying a load equal to 7 tons per square inch when under steam-pressure. At that time he used chiefly Bessemer steel. He had made locomotive boilers for the Maryport and Carlisle Railway in 1861, solely out of Bessemer steel, and he had never used much finer material. It was not a question of who made the metal. Many persons would remember the time when Staffordshire iron was made within a small distance of where the coal, the ironstone, and the limestone were obtained. Where it was made by one set of men, tolerably uniform Staffordshire iron was produced; but, in the present day, so-called Staffordshire iron was made out of Middlesbrough pig, Northampton pig, Lincolnshire pig, or any pig-iron that could be obtained cheaply. An exact, intelligible, measurable alloy, that would give the same results, should now be the aim of makers. He had made one hundred and fifty thousand experiments or tests of steel, and was bound to say that he could thoroughly depend upon the material if only the composition was in accordance with his requirements; otherwise both money and time were wasted. The Author appeared to have thought that steel ought to be stronger, and that if it were made in larger ingots that object would be accomplished. He was sure that the Author had been entirely mistaken, and that

Mr. Adamson.

Mr. Adamson. larger ingots would be less uniform. Those who remembered the

FIG. 10.



Paper on "The Treatment of Gun-Steel,"[1] and the experiments

[1] Minutes of Proceedings Inst. C.E. vol. lxxxix. p. 114.

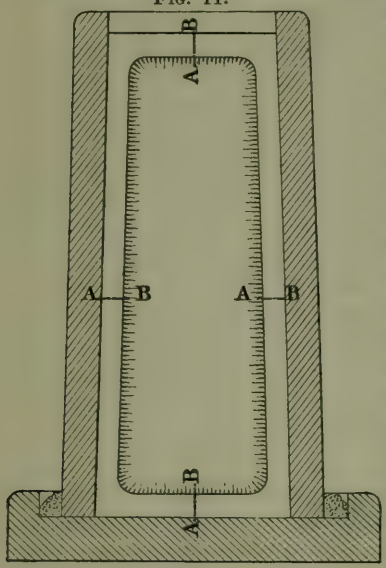
conducted by Mr. Vickers as to the composition of ingots, would recollect that the ingot, at the bottom and up the sides, and over the top, was of tolerably uniform composition as far as carbon was concerned.[1] The shell was chilled and cooled quickly, and the elementary compounds were fixed and did not vary much; but the carbon increased from the middle of the ingot upwards, the bottom portion of the centre of the ingot losing part of its carbon, while an increased quantity was found in the upper portion, to near the top, the greatest variation being from 0·22 per cent. to 0·72 per cent. and 0·78 per cent. In Figs. 10, 11, and 12, the letters A B had reference to the thickness of the chilled steel in the cast ingot, the inner or central portion being that which remained much longer liquid, and hence dissociation took place as the ingot cooled, and concurrently with the production of blow-holes by the outer shell of the metal preventing it from following the contraction of the central metal. All the elementary compounds hardened, and as they did so they gave tensile-strength, but not quite in the same relative proportion. A large plate, made from such an ingot, would not possess anything like uniformity. It was sought to get that quality by punching, by stretching, and by drifting, which, he was bound to say, was a rude, destructive, unreliable system, and, as appeared from the discussion, not convincing. Now, if dissociation occurred with carbon, taking its specific gravity as equal to that of a diamond, or 3·5 as against steel 7·85, how much more might an irregularity in composition be expected when sulphur and phosphorus were the alloys? For sulphur had a specific gravity of 2·00, and phosphorus a specific gravity of 1·77, while their melting-points might be put down as sulphur, 239° Fahrenheit, and phosphorus 112°, compared with steel 2,550°. This illustrated the tendency to produce ingots anything but uniform, and which had given rise to innumerable troubles in the hands of the manufacturer, and no subsequent testing of small fragments taken from a plate would help the manufacturer to secure a uniform material, either by testing, washers, hoops, or specimens taken for tensile-experiments. All such investigations, as had been so elaborately conducted by the Author of the Paper under discussion, might be summed up by the old adage of "locking the stable door after the horse had been stolen." It was difficult to get an ingot that did not possess uniformity in its manganiferous compounds, as the specific gravity of manganese was 8·0, or very near that of steel itself, whilst its

Mr. Adamson.

[1] Minutes of Proceedings Inst. C.E. vol. lxxxix. p. 124, Fig. 1.

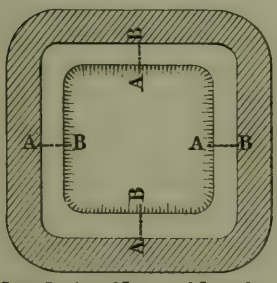
r. Adamson. melting-point was at a somewhat higher temperature, and the specific heat did not differ much from steel. It was equally difficult to get an ingot uniform either in its carbon, sulphur, or its phosphorus. Was it likely, after an hour or two or more required for the cooling of a large ingot, say 2 feet square, that the lighter alloys would remain as a perfectly homogeneous mixture? He held that it was practically impossible. All necessity for investigation would disappear if the ingot was of uniform composition. He did not believe that any amount of work would turn a bad ingot into a good one. Work, such as the Whitworth process of compression, might be put upon an ingot, which work he preferred to call consolidation, and strength might be developed by a single force; but if the specific gravity of the metal could not be increased, if it could not be made denser or more homogeneous, with greater compression than was due to ordinary fair working, it was not likely that any further increase of strength would be developed. It might be regarded as a fundamental principle that strength followed closely upon density when the alloying compounds were similar and uniform. But it did not entirely depend upon that, because hardness, developed by rapid cooling, rolling, and hammering, produced an effect upon the surface, and to some extent altered the atomic condition of the metal. What was the steel maker to do to escape the difficulty? It was stated in the Paper that if the ingots were made larger, and more labour was put upon them, there would be a better result; he was sure there would be a worse result, and that the process would be much

Fig. 11.



Vertical Section of Ingot and Ingot-box.

Fig. 12.



Cross-Section of Ingot and Ingot-box.

more expensive. If he asked a plate-maker for a plate of uniform composition, he should feel certain the plate would be of uniform strength and endurance, upon which he could rely. That had been his experience in the working of steel. He would venture to suggest that steel-makers should not take the advice of the Author, but should make ingots rectangular for all such purposes. Such an ingot, as shown by Fig. 13, would fix the alloy up to a certain thickness, and was preferable to the ordinary form of ingot. The whole outer chilled surface, with so little metal at the centre, was likely to have all the alloying compounds fixed and determined, without any variation either laterally or vertically. But the rectangular ingot had another advantage. The advantage claimed for the flat ingot (Fig. 13) was that the contraction of the interior could be followed. Being flat and easily influenced by the rapid cooling and consequent contraction, it dragged in the sides instead of remaining fixed. The cooling or chilling would very probably be up to 3 inches deep, and if the ingot were made 6 inches thick it would, in his opinion, be comparatively uniform, and no subsequent operations would make it better or worse. The inexperienced user might assert that steel was a metal that gave rise to anxieties. Looking over his books recently, he had found that the number of iron boilers made formed about 0·75 per cent. of the number of steel boilers, and, strange to say, they were either used by ironworks or by a government. Whether there was some interest at work, or only a want of knowledge, he did not know, but he agreed that there had never been a metal equal to mild steel, properly made, which, in fact, met all requirements. When he endeavoured, about 1875, to ascertain the percentage of losses of steel plates used in the manufacture of steam-boilers, he had then made over one thousand steel boilers, to assist a large manufacturing steel company in inducing the British Government to adopt steel, he found that he had lost one plate in three thousand five hundred as received from the house in question, and that one plate had been returned without his knowledge, and he was convinced the failure had been due to some fault of his own workmen. With such a metal lamination, unless it arose from the vacuous cavities to which he had referred, could not exist, there being no cinder, as in wrought-iron, to produce it; but interposed cinder would, he thought, reduce the

Mr. Adamson.

FIG. 13.

Cross-Section.

Mr. Adamson. security of wrought-iron to the extent of the square of the quantity. In the case of an iron plate containing 3 per cent. of cinder, there would be a loss of 9 per cent. of strength, at least; but then the greater diffusion of cinder material had to be taken into account, beside its irregular distribution occasionally to such an extent as to reduce the value of the metal 60 or 70 per cent. in the opposite direction to the fibre. How did this affect a bar? The investigation of the strengths of bars had been partly the business of his life. He knew that a good Middlesbrough bar would carry an ordinary tensile-strain or load of 22 tons per square inch, that it would take a permanent set at a fairly good load, and that it was a moderately good enduring piece of metal. But what about its transverse strength? His experience was that a bar 6 to 8 inches wide would break down at 8 tons, instead of 22 tons, per square inch, the intermixed cinder distributed by rolling in a longitudinal direction cutting off, as it were, atomic cohesion in a lateral direction, and hence its reduced transverse carrying power. He was in the habit of welding 600 or 700 feet of steel-plates per week, and he did not think that he lost any plates, or perhaps only one plate or so, in three months. When his experience was confined to iron, his return of failures was 12½ per cent. of the total receipts at the works. A trustworthy metal could be obtained when the iron was alloyed to the extent of about 0·75 per cent. of the ingredients he had named. A metal carrying 30 tons per square inch, elongated in 1-inch sectional area, about 28 per cent. By adding 0·35 per cent. of carbon, 0·65 per cent. of manganese, and with the other three alloys not exceeding 0·15 per cent. in the aggregate, the metal might be raised to sustain a steady load of 60 tons per square inch, but such material was unfit, and not suitable to resist concussive or percussive force, or great vibration or shock when loaded. The ductility, measured by the elongation, might be estimated, as a maximum, at 12 per cent., much less than one-half of the more ductile, weaker metal. It was useless to seek strength where great dependence was wanted. Great reliability in iron or steel could only be obtained with the metal low in alloying compounds. For a boiler-shell he preferred a strength of about 33 tons per square inch, because the metal was not greatly punished, and it worked quietly under pressure. In three thousand steel boilers of his construction, there had not been one accident in the subsequent working, at pressures from 50 lbs. to 250 lbs. per square inch. This was about the best testimony he could furnish in favour of steel, namely, its enormous endurance and its increased trustworthiness, as the heat

was raised up to about 400° Fahrenheit. That was the kind of steel boiler wanted for triple and quadruple-expansion engines for marine purposes. The measure of endurance, or the pressure worked at, was not quite the point; it was a question of what temperature the metal would endure before it deteriorated, and he put that down at 430° Fahrenheit. When he had the honour of making known the infirmity of all alloyed iron and steels, in his Paper "On the Mechanical and other Properties of Iron and Mild Steel,"[1] read at Paris, he had the same thorough conviction as at present, that the infirmity at colour-heat increased in proportion to the quantity of alloying ingredients, and also of cinder. The difficulty of working a very strong metal plate was increased in every direction, in proportion to its strength, and if it was punished by local heating and labour, without being rendered quiescent by annealing, trouble would follow, and the plate would fail from its stubbornness and want of ductility. Mr. Adamson.

Mr. Sidney H. Wells, in replying on behalf of the Author, desired to acknowledge the consideration which the Paper had received, at the hands of the President and the members, in view of the unfortunate circumstances under which it was presented. The very kind remarks made on the subject by the various speakers would be highly valued by Mr. Goodall's relatives when they read them. It would not be expected that he should reply as fully as the Author himself would have done. Mr. Goodall used to say that he expected the adverse criticism of every steel-maker in the kingdom, and perhaps the remarks of one or two of the speakers had justified his apprehension. He would have taken a great delight in replying to the criticisms of the members, and they would certainly suffer by his absence. With regard to the punching of plates, the Author did not mean to say that in 1875 steel plates were punched throughout the country; he only stated that they were punched in the works over which he was Manager. Mr. Ellis had stated that the Author, if he had annealed the plates, would not have found that in some cases the punching was attended with a sound like that of a pistol, and in other cases that the metal appeared like lead. He imagined Mr. Ellis did not intend to say that the plates should have been annealed before punching. He had made inquiries on the subject, and he had found that in every case where a steel plate was used under the Author's direction and was punched, it was annealed afterwards. With reference to Mr. Ellis's enquiry as to the meaning Mr. Wells.

[1] The Journal of the Iron and Steel Institute, 1878, p. 383.

Mr. Wells. of the tempered bending-test, he had ascertained that it meant what Mr. Ellis had suggested, that a piece of steel was made hot, dipped into cold water, and then bent. Mr. Reynolds had confessed to not understanding the Author's remarks on compression. What the Author had tried to do was to ascertain to what extent the compression due to punching was injurious or otherwise. He certainly recognized that that was not the greatest amount of compression in steel when converted into boilers, and he had referred to the subject several times in his Paper. Mr. Stanger had asked the meaning of the words in the Tables "elasticity began." He hoped that Mr. Stanger would not believe that the Author had no proper idea of the elasticity of material. Of course he knew well enough that elasticity was a property which commenced as soon as the slightest strain was put upon the material, and the term used in the Table was, no doubt, a misnomer. It should have been stated that elasticity became measurable at 3 tons, 9 tons, and so on. The fact of its not being measurable before showed that the apparatus used was not as accurate as that which Mr. Stanger would use, and he did not think that that would be expected. The method of measuring extension adopted by Mr. Goodall was to punch two small marks near the centre in the test-pieces, at the required distance apart, and then to use an ordinary pointed gauge accurately worked to that distance. While the strain was being put upon the machine, one point was kept in one mark, while the other was kept moving in a line at right-angles to the long axis of the test-piece. When he noticed that the line became appreciably thicker he said that the extension was beginning, it was then measurable. Mr. Stanger had gone so far as to say that the Author had spent an enormous amount of time and trouble without advancing the object of the inquiry. But he had never supposed for a moment that his drifting-test would supersede the tensile-test. His main object was to find out, if possible, a test which would give some idea of the nature of the material in close contact with a crack or a faulty part. He knew that that could not be done with the tensile-test. He had a very high opinion, as every engineer ought to have, of the excellent testing machines to which Mr. Stanger had referred, and he never for a moment supposed that his own tests would be compared to them. Several questions had been asked as to the way in which the washers had been cut out. He had recently gone over the works where the Author was Manager, and had seen exactly how the experiments had been conducted. The first thing done with a boiler-plate to be tested was to drill a small

hole by a drilling-machine, next to get an ordinary arbor and cutter and take out a part to the depth of about $\frac{1}{16}$ inch, and then to use an ordinary trepanning hollow-drill and trepan the washer out. The washer was held in a pair of jaws, drilled with an accurate twist-drill to the size required, and then put upon a mandrel and turned up accurately in a lathe. He was told that the measurements were made after turning by a micrometer screw, and that as much care as possible was taken to get the washers all exactly the same size. It would be apparent that in a few cases there might have been some slips of measuring, and as a representative of the Author he certainly should not like to undertake the task of attempting to find out the elongation in the enormous number of washers that were treated. The washers were pressed against one end of a hydraulic ram, and the drifts were forced through by a spindle advanced uniformly by suitable gearing worked from the shop-engine, beginning with a small one and going on to a large one till the washer broke. The bursting-pressure was measured as the mean of the readings of two pressure gauges connected to the ram-barrel. It was obvious that the figures were not to be depended upon very accurately, because no allowance was made for the friction in the ram between the gauges and the washer. The washers were afterwards measured by a taper gauge, about $\frac{1}{16}$ inch thick, graduated to $\frac{1}{32}$ inch, several positions being measured with each hole, and an allowance made for the extension due to bursting. It would be out of place for him to criticise, as the Author would have done, the differences of opinion that had been expressed in the course of the discussion, since his own experience had been extremely limited, and he was not at present engaged in that branch of engineering. He desired, however, to do what he was quite sure the Author himself would have done, namely, to acknowledge the kindness and the assistance which he had received from the firm for whom he was Manager, Messrs. Maudslay, Sons and Field, in carrying out his experiments. He also wished on his own part to acknowledge the courtesy and attention with which they had received him in any enquiries that he had had to make on behalf of the Institution, and in getting together the test-pieces for exhibition. He would conclude by expressing a hope that the result of the discussion would be to show that the Author's labours, and the attention given to them by the members of the Institution, had not been wholly in vain.

Mr. Wells.

Correspondence.

r. Gilchrist. Mr. PERCY GILCHRIST submitted a statement of the progress of the Basic or Thomas-Gilchrist process. The total production of steel and ingot-iron from phosphoric pig during the last twelve months had amounted to 1,702,252 tons, being an increase over the previous twelve months of about 388,621 tons. It would be noticed that of this make no fewer than 1,222,732 tons were ingot-iron containing under 0·17 per cent. of carbon. The production of the various countries for the twelve months ending the 31st of October, 1886, and the 31st of October, 1887, respectively, had been:—

	1886.		1887.	
	Total.	With under 0·17 per cent. Carbon.	Total.	With under 0·17 per cent. Carbon.
	Tons.	Tons.	Tons.	Tons.
England	258,466	161,908	364,526	233,358
Germany, Luxembourg, and Austria	883,859	651,523	1,102,496	826,609
France	122,711	77,141	174,271	123,049
Belgium and other countries	48,595	36,712	60,959	39,716
Totals . . .	1,313,631	927,284	1,702,252	1,222,732

Mr. Gillott. Mr. THOMAS GILLOTT remarked that the Author had not stated whether cylindrical holes had been bored in the washers; or holes having the same taper as the drifts, so that the latter did not exert a local bursting-pressure on one face before taking a bearing for the full thickness of the washers. It would appear that the holes were cylindrical, and if so, it might account for apparently worse, and certainly different, results from thin washers than were obtained from thick ones. On p. 3 the "drifting-diameter," by which he presumed was meant the diameter to which the $\frac{15}{64}$-inch hole was drifted, appeared to be about 10 per cent. less for each successive division of washers from the same plate; and if this variable extension held generally for plates of the same material and with no variation except thickness, or thickness in proportion to the diameter of hole for drifting, the scientific value of the test would be seriously diminished. The drifting-test might, however, be made a very useful one for determining local injury

in mild steel, where a silky or crystalline fracture of the burr would indicate to the practical man an uninjured or damaged material respectively. The truth and smoothness with which the holes were bored before drifting, and the lubrication of the drifts, might seriously affect the soundness of any conclusions deduced with respect to steel harder than that generally used for boilers. He could scarcely agree with the method of deducing probable Mr. Gillott.

FIG. 14.

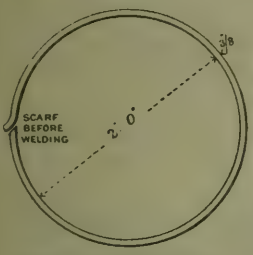
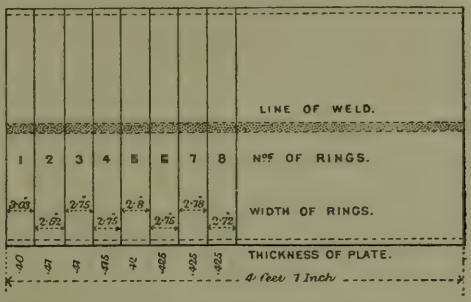
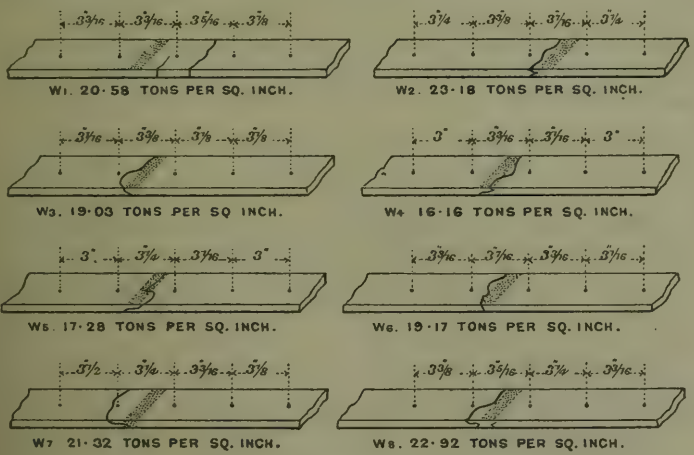


FIG. 15.


LINE OF WELD.
1 2 3 4 5 6 7 8
Nos OF RINGS.
WIDTH OF RINGS.
2·69 2·62 2·75 2·75 2·8 2·75 2·78 2·72
THICKNESS OF PLATE.
·90 ·47 ·47 ·485 ·47 ·485 ·485 ·485
4 feet 1 Inch


W1. 20·58 TONS PER SQ. INCH.
W2. 23·18 TONS PER SQ. INCH.
W3. 19·03 TONS PER SQ INCH.
W4 16·16 TONS PER SQ. INCH.
W5. 17·28 TONS PER SQ. INCH.
W6. 19·17 TONS PER SQ. INCH.
W7 21·32 TONS PER SQ. INCH.
W8. 22·92 TONS PER SQ. INCH.

FIGS. 16.

elongations under longitudinal tensile-tests from the diameters to which washers were drifted, as the unequal stresses due to drifting were more comparable with a combined bending and tensile-test rather than with a purely tensile-test; and the Table on p. 5 showed plus and minus differences of 34 and 29 per cent. notwithstanding the close average. The most important application of the drifting-test was, doubtless, to determine the condition of

Mr. Gillott. welds, or parts worked hot for flanging; and he appended the results of some tests made a few years ago on a welded steel boiler-flue, which fully corroborated all the Author's statements as to the anxiety which might be caused to those on whom the responsibility of detection fell. A Siemens-Martin mild steel plate, 6 feet by 4 feet 1 inch by $\frac{3}{8}$ inch full, was rolled, sheared, annealed, one scarf edge thinned down, the other edge laid back, and the plate bent to 2 feet in diameter (Fig. 14). The tube was heated externally and welded by hand hammers in short lengths of 3 to 4 inches at once, every care being used to keep the welded part warm during the process of welding, so as to avoid contraction strains; and after welding there was no appearance of any defect inside or outside. Eight rings about 3 inches wide were cut off in the lathe, numbered, as shown by Fig. 15, and eight strips about 2 feet long, having the weld in the centre of each, were cut out, heated, straightened, marked off into 3-inch spaces, and tested. Figs. 16 showed the strips after testing, the shaded parts representing the position of the scarf laps, with the fractures and elongations as indicated. The breaking-stresses per square inch were all calculated on the original thicknesses of the respective strips, and without allowances for local alterations at the welds.

The appearances of the strips, after straightening and before pulling asunder, were :—

W_1. Sound, inside face pitted.
W_2. „ surface good.
W_3. „ but scarf mark visible.
W_4. Surface pitted on inside face, scarf edge visible, and open 1 inch from edge. Slight flaw on outside face $1\frac{1}{2}$ inch from weld, $\frac{3}{4}$ inch wide, and on the same edge as the inside scarf.
W_5. Surfaces good, scarf mark 1 inch long in the centre of the strip on the inside face.
W_6. Surface good, slight scarf mark in the centre of the strip on the inside face.
W_7. Quite sound and surface good.
W_8. Quite sound, but pitted with a few scale marks on each side of the weld about $\frac{1}{16}$ inch deep.

The appearances of the strips under and after test were :—

W_1. Broke 3 inches from the centre of the weld, but fracture also commenced on one side at the weld. Crystalline.
W_2. Commenced to break on one side, and bent laterally $\frac{3}{16}$ inch in

15 inches. Broke just outside and 1 inch from the centre of the weld. Scarf edge on one corner just visible; appearances of burning 1 inch from the edge $\frac{1}{16}$ inch deep. Fracture silky. Mr. Gillott.

W_3. Broke on one side of the weld, but through scarf; fracture silky where sound.

W_4. Broke at the weld. Scarf mark averaged $\frac{1}{16}$ inch deep across the bar. The fracture was silky where sound, but the surface was not clean.

W_5. Broke at the weld through the scarf. Slight defect where scarf mark was visible; the surface of the fracture was not clean but silky.

W_6. Slight defect where the scarf mark was visible. Broke at the weld; silky where sound.

W_7. Broke just beyond the weld; fracture silky and almost perfect.

W_8. Scarf edge opened at 18 tons per square inch; fracture commenced on the same side as the scarf; broke at one extremity of the weld; bent laterally $\frac{5}{16}$ inch in 15 inches; fracture silky.

The tests of solid strips cut from the rings Nos. 1, 4 and 8 averaged 27·23 tons per square inch, 26·14 per cent. elongation in 10 inches, and 50·85 per cent. contraction of area. As to the Author's remarks on annealing, it was not quite clear whether he intended to express the opinion that annealing was of no use after rolling and shearing plates, or only after they had been worked hot; nor was it clear whether the plates experimented on had been annealed before the Author worked them. After having had many troubles by omitting the process of annealing after rolling and before working, he could not agree with the Author's conclusion on p. 16 if it was intended to apply generally, and could only partially agree with him if he considered it unnecessary to anneal after local heats on plates that had been annealed before working. The object of annealing was to remove any straining action that might have been set up in different parts of the same piece; and the testing of small washers removed from those parts, and consequently relieved from the general state of strain, would not prove anything, in his opinion, except the effect of annealing the washers, and not the plate from which they were taken.

Mr. Charles H. Haswell observed that steel, compared with iron, for wear and resistance to the stress to which a steam-boiler was exposed, possessed the following elements: 1. It was more Mr. Haswell.

r. Haswell. homogeneous in structure. Hence its deterioration by oxidation, when exposed to salt moisture or bilge-water, was uniform; whilst wrought-iron, being more or less laminated in structure, was, when exposed in a like manner, subject to become pitted and fissured. 2. It was somewhat lighter for equal resistance to stress, and, when of a proper hardness and temper, would flange with more certainty than iron, as the latter was liable to be laminated, was locally defective, and constructively brittle. Regarding the relative merits of annealing and unannealing:—so much, in his opinion, depended upon the manner of annealing, that, if the plant and the operation were not all normal, in capacity, and manipulation, he doubted the general benefit of annealing; for, unless the plate was wholly and equally heated and cooled, there would be local shrinkages, which would impair the homogeneity of the structure of the metal. Further, if the plates were accidentally or injudiciously heated to a high temperature, the normal structure of the metal, unless restored by being drawn out as between rolls, or under a hammer, was virtually impaired. As regarded, then, the comparative merit of open-hearth steel, he entertained a very decided opinion. Experience in the United States of America was in its favour, and especially so when the steel was low in carbon, with an ultimate tensile-strength of 50,000 to 55,000 lbs. per square inch, and an elastic limit of 35,000 to 37,000 lbs. Finally, no other than open-hearth steel was used for boiler-plates in the United States.

Ir. Holden. Mr. JAMES HOLDEN was of opinion that steel in use in boilers, especially in locomotives and in boilers of marine type in which very high pressures were used, and where the trips were short and the fires drawn daily, underwent some changes of structure.

Ir. Stoney. Mr. BINDON B. STONEY observed that the present system of testing plates and bars at the makers' works was anything but satisfactory. For example, a few years since a large iron barge was built under his directions by a well-known firm of shipbuilders, and the contract provided that the testing should take place under special inspection at the works where the iron was manufactured. Under this contract the breaking-weights of several plates and angle-bars were duly certified to have varied from 25 to 34 tons per square inch, with a good amount of ultimate set after fracture. The exceptional strength of this iron caused suspicion, and on re-testing the same in another machine which had been found sensitive and accurate, the tests, although showing that the material was of good quality, came out much lower: this was to be expected,

since 34-ton ship iron was rather a rare commodity. In this case the evidence probably indicated that the maker's machine was inaccurate; otherwise an unpleasant feeling would arise respecting the competency of some of those concerned. In a more recent instance, mild-steel plates were supplied by a well-known maker, and they were tested at his works and certified by him. On re-testing these plates in an accurate machine, their tensile-strength proved to be from 2 to $2\frac{1}{2}$ tons per square inch lower than by the maker's certificate, and the maker having disputed this, samples were sent to Mr. Kirkaldy, M. Inst. C.E., whose tests corroborated those made in the second machine. In this case, it seemed a reasonable inference, either that the maker's machine was inaccurate, or that the tests were hurried up too fast, which was extremely likely to occur in the pressure of manufacture. Mild steel would support for a short time, just before fracture, a load exceeding its actual breaking-weight, stretching quickly under this load; and it was highly probable that frequently sufficient time was not given for steel to stretch slowly up to the breaking-point, which a test-sample would do when a lower weight was applied, provided sufficient time was taken with the experiment. It seemed, therefore, desirable that some other method of testing should be provided than that generally demanded by steel makers, namely, at their own works before delivery, as they objected to supplying material subject to test by the engineer or purchaser at his place of business. Possibly licensed public machines and certified inspectors, similar to those controlled by the Board of Trade for chain-testing, would meet the difficulty; but it was one that demanded the serious attention of the profession.

Mr. Stoney.

Mr. Sidney H. Wells, in reply to the correspondence, observed, as to the way in which the washers were drilled, that the finished hole was bored with an ordinary $\frac{15}{64}$-inch Morse twist drill, after which the washer was driven upon a slightly tapered mandrel, and the outside diameter accurately turned to the standard size, so that the holes were perfectly central and practically parallel, causing possibly the local bursting-pressure referred to, when first pressed by the drift. All washers were examined before testing, and if the holes did not seem true or smooth, or any other fault was discovered, they were rejected. The Author's practice was to anneal every plate which had been in any degree locally heated during working; but he did not anneal plates after rolling or shearing without being heated. The plate shown by Fig. 1, p. 9, was the only one experimented upon which had been annealed before it failed. In the other cases, failure occurred during

Mr. Wells.

Mr. Wells. working, and therefore before annealing; hence, washers cut from these plates were tested as taken from the plates, unannealed, and after separate annealing.

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17 January, 1888.

GEORGE B. BRUCE, President,
in the Chair.

The discussion upon the Paper, by the late Mr. Hamilton Goodall, on the "Use and Testing of Open-hearth Steel for Boiler-making," occupied the whole evening.

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24 January, 1888.

GEORGE BARCLAY BRUCE, President,
in the Chair.

(*Paper No. 2276.*)

"The Erection of the 'Jubilee' Bridge carrying the East Indian Railway across the River Hooghly at Hooghly."

By Sir BRADFORD LESLIE, K.C.I.E., M. Inst. C.E.

GENERAL.

At the site of the Jubilee Bridge the River Hooghly is 1,200 feet in width at low-water; this is the narrowest part for some distance above, while below bridge the width is everywhere greater than at Hooghly. The site was selected partly on account of the small width to be bridged and partly for other considerations. A section of the site is shown by Plate 1, Fig. 1. The river-bed on the Hooghly or right side is 66 feet deep below datum, or mean sea-level. The right bank is well above the highest flood-level. On the left side the river is comparatively shallow, and there is a wide stretch of low ground which is inundated in the flood season, and which no doubt formed part of the main channel when the Damoodah River flowed into the Hooghly at Magra, some 5 miles higher up. The deep channel on the Hooghly side is scoured out to the clay by the flux and reflux of the tide, while the depth on the left side of the river varies with the movement of the sand or silt which there forms the bed of the river. In the freshets a variable thickness of silt is displaced, sufficient to adjust the sectional area of the river to the flood water to be discharged. When the floods are strong the river-bed is removed to a depth of 29 feet or more below datum.

The tides vary from mean sea-level or a foot below in the dry season to 20 feet above in the freshets; the maximum velocity of the tides is $4\frac{1}{2}$ miles per hour when the flood-tide comes in with a strong bore, and $5\frac{3}{4}$ miles an hour on the ebb-tide in the

freshets; there is never any actual upward current at that season, but the water-level rises about 3 feet at spring-tides.

There is a very large navigation on the river, country craft of unwieldy proportions and but little under the control of their crew, also the steamers and flats (vessels of 500 or 600 tons burden) of the Inland Navigation companies, and passenger steamers which ply between Calcutta and Kulna, 45 miles above Hooghly.

The bridge is for a double line of railway (5 feet 6 inches gauge) in one roadway carried between the main girders. One advantage of including both lines on one roadway is horizontal stiffness to resist the force of the wind in cyclones or storms. It also simplified construction, and reduced the width of the approaches, abutments and piers, which must have been greater if a central girder or girders had been used.

The superstructure of the bridge is divided into three sections, as shown by Fig. 1, spanned by girders of the triangular type, with curved top booms and straight bottom booms of the ordinary box or trough section. The vertical struts are composed of four angle-bars back to back, and inclined ties of double flat bars, both stiffened by cross-bracing. The roadway for the double line of railway is carried between the main-girders on four longitudinal plate-beams or girders, supported by cross-girders, riveted to the bottom booms of the main-girders, at intervals of 30 feet, which is the length of the panels or bays of the main-girders. The girders are strengthened by horizontal diagonal bracing at roadway-level and overhead. The cantilever has a complete deck-plate over the entire roadway-platform, and is strengthened in addition by overhead transverse diagonal bracing between the vertical struts. The girders of the main side-spans have a deck-plate on the roadway at each end. The central double cantilever is 360 feet long, and the two main side-spans are each 420 feet long, or a length of 1,200 feet altogether, between the centre of the bed-plates on the side abutments. The total weight of steel in the superstructure of the bridge, including the standards on the river piers, is 3,876 tons.

The cantilever is carried at a height of 53 feet clear above datum on two river piers pitched 120 feet 6 inches apart from centre to centre. This arrangement has several advantages: 1st. It locates the piers in comparatively shallow water. It will be seen from Fig. 1 that if an ordinary bridge of three equal spans of 400 feet each had been adopted, the pier on the Hooghly side would have fallen in 40 feet of water at low tide, a depth in which, knowing the force of the tidal bores and floods, the Author was

not prepared to take the responsibility of pitching and sinking a large caisson. 2nd. The site adopted for the piers leaves the widest spans, 520 feet on each side of the river piers, for navigation; the country craft, which either sail, are rowed or towed by the crew, or drift on the tide, generally prefer the left or shallow channel, as the stream is there moderate, while steam-vessels and flats use the deep channel. A third advantage of carrying the central section of the superstructure on two piers, 120 feet 6 inches apart, was the convenience of erection of the cantilever girders; the central 180 foot-length of these girders was erected on a temporary staging (Plate 1, Fig. 4) carried by the river piers, and the remaining 90-foot length at each end was built out without staging by means of derricks. If a central span of 400 feet had been adopted, the erection of the girders of such a span would have required special plant and appliances. The girders of the main side spans were built on the approach viaducts and were transported into position as will be hereafter described.

River Piers.

The site of the river piers is in about 27 to 30 feet of water at low spring-tides in the dry season; the bed of hard yellow clay is met with at a depth of about 89 feet below datum at this part of the river, and the piers had to be sunk through about 60 feet of silt to reach the clay. The piers are 66 feet long, up and down stream, by 25 feet wide, with semicircular ends and flat sides. To sink these, two wrought-iron caissons, 108 feet high by 66 feet long by 25 feet, with semicircular ends, and each weighing 453 tons, were provided. The caissons were divided into three excavating chambers open from top to bottom, by two transverse compartments each 15 feet wide on the longitudinal axis of the caissons (Fig. 2). These compartments afforded the buoyancy necessary for floating the lower portion of the caissons from the shore, where they were built, to the site of the piers, and until they reached the bottom of the river. The semicircular ends of the caissons were strengthened by horizontal shelf-plates 3 feet broad, at vertical intervals of 4 feet, the space between these being filled with brickwork as the caisson went down. For a height of 36 feet above the bottom of the caisson, the central chamber also had two lateral buoyancy compartments, which contributed to the stability of the caisson while afloat, though they reduced the area of the central excavating chamber to 10 feet by 17 feet, while the end chambers were semicircles 19 feet in diameter. In the upper portion of the caisson the lateral compartments were re-

placed by shelves 3 feet broad at vertical intervals of 4 feet. The combined horizontal area of the three chambers was 480 square feet, being 32 per cent. of the total area of caisson, which was 1,516 square feet. To facilitate sinking through the river-bed the lower portion of the caissons and of the transverse compartments was built with internal inclined surfaces, extending from the bottom of the caisson to a height of 12 feet. The bottom of the caisson is an angle-iron 5 inches by 5 inches by $\frac{5}{8}$ inch, which, with the vertical skin plate and 3 feet by $\frac{5}{8}$ inch external stiffening plate, forms the cutting edge; the angle-bar was filled by bevelled timber inside so that there was no horizontal surface at the bottom of the caisson. The wedge spaces between the internal inclined plates and outer vertical skin of the caisson were filled with cement concrete. The lower 16-foot length of each caisson was riveted up complete on the river-bank, and launched on ways laid for the purpose, and when afloat it drew 9 feet of water. The upper portion of the caisson was built up in rings or zones, each 4 feet high and weighing 15 tons; these were connected with the completed portion of the caisson by internal $3\frac{1}{2}$- by 3-inch by $\frac{7}{16}$-inch angle-bars, and $\frac{7}{8}$-inch rivets, 3-inch pitch. The skin or outer plate of the caisson was $\frac{5}{8}$ inch thick for a height of 44 feet, $\frac{1}{2}$ inch thick for a further height of 32 feet, above which it was $\frac{3}{8}$ inch thick.

Pontoons.

To afford a working platform for men and material, and to enable the caissons to be pitched correctly in position, two pontoons, each 225 feet long by 26 feet 6 inches wide by 9 feet deep, with transverse bulkheads 72 feet apart and equidistant from the centre of the pontoons, also a central longitudinal bulkhead, were provided. The bottom and bilge plates of the pontoons are $\frac{5}{16}$ inch thick, and the side and deck plates $\frac{1}{4}$ inch thick. The skin is riveted to the longitudinal angle-bars 3 inches by 2 inches by $\frac{3}{8}$ inch 1 foot 5 inches apart, secured by reverse angle-irons to $3\frac{1}{2}$- by $2\frac{1}{2}$-inch by $\frac{3}{8}$-inch transverse frames at centres 9 feet apart. This system of longitudinal framing gave the pontoons great strength; they were built at the works on the river-bank, and were launched sideways on ways laid under the transverse bulkheads with a length of 75 feet overhanging at each end. The weight of each pontoon was 154 tons. The pontoons were equipped with two powerful capstans, one at each end of each pontoon, or four in all, besides bollards, fair leaders, &c.

The pontoons were joined together at a distance of 60 feet

from centre to centre, leaving a clear space of 33½ feet between them. The connection was by means of an intermediate iron platform, level with the decks, 37 feet broad in the length of the pontoons; the platform was not central longitudinally, but situated forwards, 37 feet clear of the centre of the pontoons, so that the space between them formed a kind of dock closed at one end by the intermediate platform. The pontoons were connected by an overhead staging constructed of old rails fastened together by bolts and castings; the two main trusses of this staging, 33 feet 6 inches deep, were fixed to the decks of the pontoons immediately over the transverse bulkheads, and therefore 72 feet apart from centre to centre. The pontoons were also joined by auxiliary trusses nearer to the ends, the object being to preserve the decks in one plane. The main trusses had cantilever ends overhanging the outside of the pontoons 22½ feet, and were connected at the top by twenty-seven girders at intervals of 5 feet from centre to centre, below which, at a clear interval of 3 feet 6 inches and 23 feet above the pontoon decks, were suspended three transverse railways with the same interval, 25 feet, between them as the excavating chambers of the caissons. These railways extended the entire width of the main trusses overhanging the sides of the pontoons 22 feet (Fig. 2).

As before stated, the main piers are 120 feet 6 inches apart or 95 feet 6 inches in the clear; the total breadth over the pontoon decks and the intermediate platform was 86 feet 6 inches; and, when the pontoons were moored in position at the centre of the bridge, there was a clear space of 4 feet 6 inches between the gunwales of the pontoons and the sides of the caissons as moored at the sites of the piers. The overhead transverse railways commanded the centres of the caissons, so that material brought into the dock between the pontoons on an iron punt could be lifted by crab-winches travelling on the overhead rails, and deposited on either caisson or on the deck of the pontoons. This arrangement, coupled with double sets of excavating gear, enabled work on both caissons to be proceeded with simultaneously, by which a saving of valuable time and an economy of labour were effected; as the several sets of men required for erecting, riveting or excavating did not have to wait upon one another, but could always be transferred from one caisson to the other. One pontoon contained the steam-power and pumps for excavating earth from the caissons, the other the steam-power for driving the boring gear. The pontoons were cross-moored by four 3-ton anchors with 1¾-inch chain-cables adjusted by chain-tackles, by

which a considerable strain was always kept on the moorings, the rise and fall of tide being allowed for by the long scope of cables; thus moored, the pontoons kept exactly in position without drifting or being otherwise affected by the tides.

The lower 16 feet of the caissons were launched as described, and towed at slack-water into position alongside the pontoons. The caissons were moored by means of girdle- or bridle-chains, suspended round them at a height of 10 feet above the cutting edge by rope lashings passing through cast-iron pipes bolted to the inside of their skin, in which holes were cut to allow lashings to pass through the pipes; by this arrangement when the caissons were pitched the lashings could be cut by the diver, and the girdle-chains removed, and there was no external projection to impede the sinking of the caissons through the earth. The bridle-chains of the caissons were connected by 1-inch chain-tackles to up- and down-stream moorings, 3-ton anchors and 2-inch chain-cables; by this means the up-stream and the down-stream position of the bottom of the caissons could be adjusted, by heaving on the hauling part of the chain-tackles from the pontoon capstans. Breast moorings of a lighter description for adjusting the lateral position of the caissons at the bottom were also used. It was necessary to hold the caissons by moorings near the bottom, as on account of the great grip of the tides on the open bottom and transverse partitions of the caissons, it would have been impossible to control them when drawing over 30 feet of water merely by topside tackle.

The sinking of the caissons through the water was effected by the weight of additional caisson rings, brickwork between the shelf-plates of the semi-circular ends, and a certain amount of concrete deposited in the buoyancy compartments. As the top side of the caisson approached the water an additional 4-foot ring was conveyed on the iron punt into the dock between the pontoons, lifted by crab-winches travelling on the overhead transverse railways and deposited on the top of the caisson. After riveting up and caulking, an additional depth of 4 feet of brickwork between the shelf-plates was built as before; and when the immersion became considerable the flat-sided buoyancy compartments had to be strutted to resist the external pressure of water. As the cutting edge approached the bottom of the river care had to be taken that it did not ground at low-water. A sufficient height or free-board of caisson having been built up to allow for sinking into the river-bed and for rise and fall of the tides, the caisson was finally pitched by admitting water into the buoyancy compartments by means of siphons. As the caissons were sunk through the bed of the river the buoyancy

compartments were filled with concrete of Portland cement and stone to the level at which it was safe to bale them dry, after which they were filled with solid brickwork affording weight for sinking them through the river-bed.

On Saturday the 26th of April, 1884, just after all hands had left work, the No. 1 caisson on the west side of the river, which was afloat ready for pitching, drawing 32 feet of water, and weighing 750 tons, was caught by the bore, which on this occasion, as is frequently the case, came up with a cant across the river and thus took the caisson at an angle with its axis. The great pressure carried away the chain-lashings by which the top side of the caisson was secured to the pontoons; this, and probable dragging of the bottom breast moorings, allowed the caisson to cant still more across the tide, and the enormous strain then carried away the chain-tackles of the up- and down-stream moorings, and all the bollards and holdfasts on the pontoon decks, tearing to pieces the powerful wrought-iron blocks, in which the 1-inch chain-tackles were rove, in the most extraordinary manner. The caisson having thus cleared itself of its moorings, was carried on the bore nearly ½ mile up the river and grounded across the stream, but on tolerably hard bottom. In freeing itself the caisson gave a heavy lurch; this might possibly have been caused by its slipping out of the girdle-chains to which the chain-tackles were fast, as these chains were never recovered. The European watchman who was on the caisson at the time, was carried up with it. Fortunately the tide which did the damage was not the highest of the springs. It was difficult to approach the caisson as it had grounded in the tide-way. However, when the tide slackened a barge was secured alongside, and, by working night and day, the caisson was lightened by the removal of about 40 tons of cement brickwork, and with the assistance of strong warps hauled on by steam anchor-barges suitably moored, and with the help of the bridge steam-tender, the caisson was dragged off the bank and floated at high-water on Sunday evening. All the pontoon gear and ground moorings of the caisson being broken and lost, it could not be moored in position again. There is, however, just below bridge, on the right bank of the river, a little bay or harbour with no current and a depth of 7 fathoms at low water, and into this harbour the caisson was towed at slack water, and temporarily moored by ropes made fast to trees on the river-bank and also by anchors. There the caisson was held securely till the dead neap-tides, when, being all ready for pitching, it was towed out at slack water into position, and, the buoyancy compartments being filled by the siphons, was successfully deposited correctly in its permanent site.

The recovery of this caisson was a most fortunate circumstance; had the tides been abating instead of on the increase the case would have been much more serious.

The No. 2 caisson was pitched according to programme. Immediately a caisson was pitched the tide began to undermine it by scouring away the river-bed outside, so that it was necessary to lose no time in starting to sink it by removing the earth from the inside. The dredging of the earth was done by special boring-gear, one set in each excavating chamber, identical in principle, and indeed almost the same in detail, as that used at the Gorai Bridge [1] in 1868–69, the main differences being that the boring-gear was driven by steam instead of by air-pressure or turbines, and that the siphons through which the earth was discharged into the river were charged by Körting's ejectors instead of by air-pumps. There is no occasion to describe this boring-gear again, as its operation was precisely similar to that at the Gorai Bridge. Through the silt the caissons were sunk by boring-heads 10 feet in diameter. To check scour outside, when it threatened to overtake the sinking operations, bags filled with dense black clay were deposited in the holes scoured out; many thousands of these bags of clay were used, though the sinking having to be carried on during the flood season, when there is no slack water for many days together, it was not an easy matter to fill the holes scoured out by the tide. It was not safe to use stone rubble for fear of its working down under the cutting-edge and impeding the sinking of the caissons; the bags of clay did occasionally so get drawn in, but did not check the sinking. On one occasion the scour so far undermined the No. 2 caisson when it was 60 feet high, as to cause it to cant over to an angle of 1 in 8, and communication was established between the external water and the north boring compartment. The condition of the caisson was precarious. Heavy mooring anchors were laid out and connected by chain- and rope-tackles "luff upon luff" to the top side of the caisson, so that an estimated strain of 200 tons was exerted tending to right the caisson; then by boring steadily in the chambers which were watertight the caisson gradually righted, the tackles being constantly set up to keep the maximum strain as the caisson came over. The righting of this caisson shifted the position of the cutting edge slightly, so that the caissons are really 120 feet 10 inches apart instead of 120 feet 6 inches as originally pitched.

When the caissons got down to the hard yellow clay they stood firm on the cutting edge and did not penetrate it. The

[1] Minutes of Proceedings Inst. C.E. vol. xxxiv. p. 1.

10-foot holes excavated 8 feet in advance of the cutting edge, which were sufficient in sinking through the silt, had no effect. The boring gear had then to be lifted out of all the compartments, and two of the arms of each boring-head extended, so that they excavated holes 14½ feet in diameter, and, in fact, to a certain extent under-cut the transverse compartments. The excavation of these large holes in advance of the cutting-edge caused the clay to break in and the caisson to sink. When the cutting edge was far enough into the clay to make it safe to remove water from the caisson, the level of the water inside the excavating chambers was lowered 24 feet by special pumps, which increased the effective weight of the caissons by 700 tons and helped to sink them through the clay. The caissons were thus got down until their cutting edges were over 100 feet below datum, at which depth, being firmly embedded 10 or 12 feet in the solid clay, further sinking was stopped, and the excavating chambers were filled to a height of 46 feet below datum with concrete of Portland cement and broken stone, and above that level with solid brickwork. The concrete was lowered through the water in iron boxes with four inclined bottom leaves, or flaps, hinged to the sides and released by the disengagement of a central bolt from the lifting-chain; in this manner the concrete was deposited with very little disturbance and set very hard. The piers are of brickwork up to a height of 124 feet from the bottom of the caissons. Anchor-castings and sixteen 3-inch bolts, 24 feet long, for holding down the steel standards which carry the cantilever girders, are built into the upper portion of brickwork of each caisson.

The total dead-weight of one pier, including the steel standard and superstructure, is 12,567 tons, and the maximum incidence of the moving load, consisting of two trains weighing 1 ton per lineal foot, is 1,320 tons, or together 13,887 tons; deducting the frictional support of the river-bed on the surface of the caisson at 5 cwt. per square foot, or say 2,500 tons, the pressure on the base of each pier is 11,387 tons, or at the rate of 7·5 tons on the square foot. The normal pressure of earth and water at the same depth is 4·5 tons on the square foot.

Just before reaching the clay, the No. 1 caisson passed through a bed of about 3 feet of small stones or pebbles, much the size of Thames ballast. As there is no stone or gravel within 100 miles of Hooghly, it is difficult to say how the pebbles got there, unless it really was ballast thrown overboard by some merchant vessel in the days, upwards of 200 years ago, when Hooghly was the chief factory and port of the British in Bengal, whence the river

is called by the English the "Hooghly" to this day; it might well be that the deep channel was at the site of the piers in those days.

To protect the piers from scour, since they have been sunk about 40,000 cubic feet of heavy stone rubble, averaging 2 or 3 cwt. each stone, has been deposited round each pier, and more will be added if required, but the large-sized rubble appears to be very effective in resisting scour. The abutments are also protected by a bank of heavy stone rubble, as in high floods they are exposed to a strong current.

The steel standards, or pedestals, are simply vertical cellular structures, 30 feet high, of plate and angle-bars riveted together and secured to the brickwork of the piers by holding-down bolts and anchor-castings. These standards weigh 205 tons each, and carry the cantilever girders at a clear height of 53 feet above datum; being slightly elastic they allow for the expansion and contraction of the girders in the span of 120 feet 6 inches between the river piers.

Abutments.

Work on the abutments was not commenced until the caissons for the river piers were pitched and partly sunk, to afford the opportunity of meeting any slight inaccuracy in the location of these by a corresponding modification of the centre line; no such modification was, however, necessary, as the up- and down-stream location of the caissons was exact, and the original centre line was adhered to.

On the Hooghly side, where the deep channel runs, the bank is of stiff clay that resists the action of the water. The abutment on this side was founded by sinking an iron curb, 65 feet long by 28 feet wide by 8 feet deep. The curb had two cross partitions dividing it into three excavating-chambers, open at top and bottom. The curb was, in fact, the taper shoe of the block foundation of the abutment; it was of sheet-iron, $\frac{1}{4}$ inch in thickness, strengthened by gussets. The outsides of the curb were vertical and the inner sides inclining inwards from the cutting-edges at an angle of 60°; both sides of the inner transverse partitions were inclined. The curb was filled with concrete, on which the brickwork of the abutment was built, the sides of the excavating-chambers being corbelled over until their size was reduced to 12 feet by 6 feet. To prevent dislocation of the brickwork during sinking, it was connected with the curb by a framework or crating of angle-bars, vertical and horizontal, securely riveted to the gussets of the curb. When

sufficient weight of brickwork was built, the curb was sunk through peat and blue clay, additional brickwork being added as weight was required until it finally rested 4 feet in the hard yellow clay at a depth of 34 feet below datum. This block foundation was excavated by hand, as but little water leaked in, which was easily removed by baling. When the curb had reached the desired depth, the excavating-chambers were filled with concrete well rammed and brickwork. The neat work of the abutment started upon the block foundation at the level of 10 feet above datum.

The left bank or Naihati abutment was founded on a similar sheet-iron curb to that used on the Hooghly side; but being pitched in sand, or rather silt, through which the water percolated, the soil had to be removed from the excavating-chambers by Bull's dredgers worked by steam-winches, the weight necessary for sinking being imposed by building up brickwork on the curb, leaving openings 12 feet by 6 feet for excavating from the three chambers. When the cutting-edge of the curb reached 50 feet below datum the abutment began to hang by side-friction, and notwithstanding the addition of as much weight as possible, the quantity of stuff removed by dredging greatly exceeded the net displacement of the depth sunk, multiplied by the area of the curb. This drew in the soil from the outside, disturbing and cracking the surrounding earth for a distance of 100 feet on the land side of abutment; however, it was finally sunk through the river silt till the bottom of the curb was 73 feet below datum, or 84 feet below the river bank, a depth amply sufficient to ensure stability; and as the borings proved that no better foundation existed even at a depth of 140 feet below datum, further sinking was stopped. The excavating-chambers were then filled with Portland-cement and broken-stone concrete, lowered through the water by means of the iron boxes employed in concreting the caissons of the river piers, to the level of 33 feet below datum, after which ordinary brickwork was used. The neat work of the abutment was started on the block foundation at the level of 10 feet above datum.

Approach Viaducts.

The approach to the bridge on the right bank of the river is through the town of Hooghly, where a high price has to be paid for land and buildings, and as the height of the rails above ground is 30 feet, a solid embankment would have entailed too great an outlay for land. For this and for other reasons the approach to

the bridge is by an arched viaduct of brickwork. The total length of viaduct through the town of Hooghly is 3,280 feet, of which a length of 450 feet adjoining the bridge was specially designed for the erection of the girders of the main side span on its spandrel walls. The extreme width of this viaduct at top is 37 feet 9 inches, and the piers are 15 feet apart from centre to centre, the clear span of the arches being 10 feet 10 inches. The foundations of concrete are spread over a large area, and the whole structure was made very massive, to sustain the severe strains to which it was subjected in the erection and launching of the girders of the main side spans.

A similar approach viaduct, 450 feet long, was erected on the Naihati side of the river; on this side the height from ground-level to the rails is 43 feet. The foundation of the greater portion of the viaduct consisted of a layer of concrete at a depth of about 8 feet below ground-level, with an area of about 50 square feet per lineal foot of viaduct. In rear of the left abutment of the main bridge, however, the ground had been disturbed by excavation from the chambers of the abutment-curb drawing in the earth from outside as previously described, and to bridge over this disturbed area it became necessary to have recourse to a block foundation. This consisted of a rectangular block of brickwork, 60 feet square, with twenty-five excavating chambers each 6 feet square at the top, through which the earth was removed by Bull's dredgers worked by steam winches; the block was sunk to a depth of 10 feet below datum, or 20 feet below ground-level. The block foundation was built at the level of 12 feet above datum, on a grating or curb of old rails with wedge-timbers to serve as a cutting-edge bolted to the under side; on this rail-grating and bolted to it thirty-six vertical rails were erected at suitable spaces, with horizontal connecting rails at intervals of 5 feet, the whole forming a substantial skeleton framing as a bond for the brickwork during the process of under-sinking. The lower portion of the brickwork inside the chambers was taper to facilitate sinking through the silt, and the bottom length of 3 feet was built in cement. The total height of the 60-foot block is 20 feet. When sunk to the depth of 10 feet below datum, at which depth from its great area and mass it was considered that the block would afford a secure foundation for the viaduct, the excavating-chambers were filled with concrete and brickwork, making it a solid mass weighing some 4,000 tons. After giving time for the setting of the brickwork and concrete and for settlement, the viaduct was completed over the block foundation and connected with the abutment. A crack has since occurred between

the viaduct and the abutment, probably due to the fall of water-level in the river reducing the upward pressure on the base of the 60-foot block, as the whole of the soil is permeable and the level of saturation varies with the water-level in the river.

To distribute the load of the main girders during the operations of protruding and launching the same, the viaduct openings were double strutted under each girder, by diagonal timbers butting against 6-inch angle-irons resting in angles of set-offs at the base, and of string courses at the top of the viaduct piers, and tightened up by hard-wood wedges.

Erection of the Cantilever.

The river piers are 95 feet 6 inches apart in the clear. A temporary staging, consisting of four trusses of timber and old rails (one pair of trusses under each cantilever girder), spanning the space between the piers and projecting 30 feet outside each of the steel standards, was constructed for the erection of the central 180 feet of the cantilever (Plate 1, Fig. 4). The long struts and sills of the staging were strengthened by double-headed rails partially let into the sides of the timbers; besides adding greatly to the stiffness of the staging, the side rails served to cover the butt joints of the timbers. In accordance with the usual practice the cantilever material was sent out from England partially riveted. The girders are 30 feet 8 inches apart, from centre to centre, and 52 feet high. The total invoice weight of materials in the cantilevers is 1,465 tons. The bottom booms having first been put together on blocking on the timber staging and adjusted for line and level, the erection of the upper portion of the girders was commenced over the river piers; this enabled the girders to be to a certain extent balanced on the river piers, and relieved the load on the timber staging. The several sections, in which the materials were sent from England, were floated from the shore on the iron punts and raised by derricks into position, and temporarily connected by drifts and service-bolts until the work was sufficiently advanced for riveting. In this way the upper portion of the girders was erected until the connection of the top booms at the centre of the bridge made the central portion of the cantilever self-supporting. At the points of support on the river piers, inclined struts fixed at the base to the top of the steel standards, and riveted at the apex to the main uprights of the girders, are provided to resist the pressure of the wind in cyclones (Fig. 3). The end portions of the cantilevers, projecting 90 feet

beyond the timber staging, were erected by first placing in position a 30-foot length of bottom boom with gusset-plates attached, and suspending it temporarily by tackles, then raising and fixing the inclined suspension bars, and afterwards the vertical struts and sections of the top boom, thus completing the 30-foot bay. The derricks used were Oregon spars 70 to 90 feet in length; they were guyed from buoys moored in the river and from the pontoons, which were moored on the down-stream side of the river piers, and formed a convenient working platform. The derricks were shifted from place to place on the cantilever platform as required. In raising the sections of overhanging portions of the cantilever, it was sometimes necessary to use the derricks inclined to a very considerable angle, requiring intermediate guys to prevent sag; but with care no great difficulty was experienced in erecting and building out the cantilever girders in the manner described. The cantilever was built with an upward camber of 6 inches between the piers and the ends of the girders. When it was riveted up complete the timber staging was removed. The materials for the cantilever were received at the works in March 1886, and the whole was erected and riveted complete by the end of October, the work having been carried on without intermission during the hot and rainy season while the river was in full flood.

Erection of the Main Side Spans.

In the meantime the erection of the girders of the main side spans was in progress. These girders are 420 feet each in length, 30 feet 8 inches apart from centre to centre, and 47 feet deep over all in the middle. The invoice weight of each span was 1,000 tons. The outer, or cantilever end of the girders was formed with a step, or rebate, which rests on a corresponding bench at the ends of the cantilever girders. The inner or shore ends of the girders of the main side spans terminate in castings bolted to the sides of the end vertical plates with semicircular bearings, which rest upon 15-inch transverse steel pins, passing through holes at the bottom of a pair of pendulum links, suspended on corresponding pins carried in holes at the apex of triangular saddle castings, 9 feet 2 inches high. These castings rest upon and are bolted to cast-iron bed-plates, 10 feet long by 5 feet wide by 1 foot 10 inches deep, bedded in Portland cement on the brickwork of the abutment, and are held in position by holding-down bolts (Fig. 7). This arrangement provides for the free expansion and contraction of the girders of the side spans and cantilever, from the centre of

the river pier to the end bearing on the abutment, a length of 540 feet.

The nature of the river-bed, the great strength of the floods and tides, and the crowded navigation, made it impossible to provide a fixed staging for the erection of the girders of the main side spans, and they were therefore built on the approach-viaducts. Before commencing the girderwork, however, the railways for carrying the rear ends of the girders while being transported across the river had to be laid. These launching-ways consisted of four 60-lb. flat-footed rails, laid in juxtaposition immediately under the centre line of the main girders on each side of the viaduct, the spandrel walls of which were built up to the level of 51·50 feet above datum. The rails were laid on transverse 3-inch pine planks resting on three longitudinal baulks of teak timber, which were carefully and solidly bedded on the brickwork; the upper side of the timbers was dressed to a plain surface to receive the cushion of pine. The rails were secured to the timber by coach screws, the joints of the rails were fished and were further supported by a 5-inch by 5-inch by $\frac{3}{8}$-inch plate, let in flush with the surface of transverse pine planks. At the abutment the rails were laid on the cast-iron bed-plate direct, and prolonged to project 3 feet beyond the face of the abutment to carry forward the ends of the launching trollies when the rear ends of the girders reached the centre of the abutment. The launching-railway on the Hooghly side was level for a distance of 240 feet from the centre of the bed-plates; thence it was laid with an incline of 1 in 120 (falling towards the abutment) for a length of 90 feet, beyond which to the rear end of the girders it was level. On the Naihati side the incline was longer but not so steep. The camber blocks on which the main girders were put together were laid on the rails of the launching-ways, and with such a solid base the erection of the girders proceeded without any great difficulty. The whole of the material was raised from the ground and put in place by derricks. The bottom booms were laid with the specified camber of $8\frac{1}{2}$ inches, but it was found that the actual camber of the girders as built was somewhat less.

As erected, the forward or outer end of the girders was 15 feet behind the centre of the cast-iron bed-plate, which is 9 feet from the face of the abutment, and consequently the girders had to be pushed out or protruded 75 feet in order that the outer ends might overhang the face of the abutment sufficiently (51 feet) for the pontoons to be berthed beneath for floating them out. For this purpose it was necessary to support the forward ends of the

girders at point J on a roller platform. In the overhanging portion of the girder, J to H, the inclined tension-bars had to be stiffened to prevent them from buckling under the compressive-strain to which they were temporarily subjected. The total weight to be carried during protrusion and until launching at point J was about 612 tons, and as the sectional area of the vertical struts J F in two girders is only 41 square inches, and of the tension bars K F is only 72 square inches, it became necessary temporarily to strengthen the girders by counter-struts J E and K D. For this purpose a certain number of rivets were omitted from the gussets at J, K, E, D, and box castings, with wide flanges specially cast for each place, were inserted and secured by bolts and drifts through the holes from which the rivets were omitted. These castings were the abutments of the expanding struts, and were fixed at the exact angle to receive them. The struts were made of old rails of the double-headed section; they were formed spindle-shaped, or fish-bellied, in side elevation, and the ends were secured by through bolts to the outsides of the cast boxes between gussets. Each pair of rails was connected by $\frac{7}{8}$-inch cross bolts at intervals of 4 feet, so that, the ends of the struts having been firmly bolted to the cast-iron abutments, they could be expanded to take their share of the weight, simply by tightening the cross bolts. To prevent buckling inwards, wooden cross struts, cut to fit, were inserted at each connecting bolt after the latter had been tightened; and to preserve them truly in line, they were guyed by chains and stretching-screws to the top and bottom booms and vertical struts of the main girders. The struts at J E consisted of six pairs of rails, giving a total area of 84 square inches in section. At K D the abnormal strains were much reduced, and four pairs of rails only were required. Great care was exercised in the construction and fitting of these counterstruts, the flanges of castings were faced to fit tightly between the gussets, all holes were drilled and special cylindrical bolts were made thoroughly to fill the holes and leave no play. Thus stiffened, the main girders were perfectly relieved of the excessive or abnormal strains to which they would otherwise have been subjected, when supported at point J during protrusion, and pending launching.

Roller Bearing.

During protrusion, the main girders were supported at point J on a bearing, or sledge, of hard-wood cross timbers the full width of the bottom plates of the girders, and extending 5 feet on each

side of point J. The bottom box of each girder was stiffened by the insertion of an additional transverse diaphragm 4 feet on either side of J. The under side of the cross timbers, which were dressed to a plane surface and connected together by bar-irons let into the ends, rested upon seven parallel, inverted, flat-footed rails 10 feet long with ends slightly rounded to facilitate the entry of the bar-iron rollers $3\frac{3}{4}$ inches in diameter, on which the forward ends of the main girders were carried during protrusion. The inverted rails were secured to the hard-wood bearing by coach screws. It should be explained that from point J in the original position of the main girders to the ends of the launching-ways there were six instead of four rails under each main girder. This was in order to give bearing surface for the bar-iron rollers which were spaced 8 inches apart under the roller-bearing.

The weight at the inner or rear end of the main girders during protrusion was 438 tons, and during launching, when their outer ends were supported on the pontoons, 500 tons. It was originally intended to carry the rear ends of the girders during launching on the pendulum links, resting horizontally on 3-foot wheels revolving on the 15-inch pins, and central holes were made in these links accordingly. This would have brought a weight of 270 tons on each side of the viaduct on a wheel-base of 7 feet only. According to experiments made on the sustaining power of the soil on the Naihati side of river before the works were commenced, this weight, in addition to the weight of viaduct itself, would not have been too much for the area of foundations given; but from some settlement which took place during the construction of the viaduct, especially at the east end when the earthwork of embankment was thrown up round it, some doubts arose as to the sufficiency of the foundations to sustain such a concentrated load, and it was thought advisable to provide special trollies to distribute the load over 22 feet of the launching railway. These trollies are shown by Fig. 7, and were constructed at the works of plate and bar-iron. They were inserted between the side plates of the end boxes of the main girders. By the temporary removal of a portion of the end bottom plate of the main girders, and of two transverse stiffeners, or diaphragms, space was given for a trolly 25 feet long by 3 feet 1 inch wide by $5\frac{1}{2}$ feet deep. The end of the main girder as constructed consists of two ($\frac{1}{2}$-inch and $\frac{3}{4}$-inch) vertical plates forming the side plates of the end boxes, and to which the end bearing castings are bolted; to stiffen these, and to make the girder ends a little more substantial for handling during protrusion and launching, an additional $\frac{1}{2}$-inch plate was riveted to each side of the

girder end, and a curved transverse plate was riveted to the angle-bars of the inside of the end box. The end of the main girder was supported on the trolly, by the semicircular bearings in the end castings resting on the 15-inch steel pins, which were inserted through holes at the centre of the main side beams of the trolly; these beams were supported on two 7-inch pins passing through holes 16 feet apart from centre to centre near their ends, and through holes at the centres of two pairs of smaller inner beams, which in their turn were carried at their extremities by the 5-inch axles of four solid cast-iron wheels, 2 feet in diameter, with tread 18 inches broad, which travel on the four rails of the launching ways. The side beams of the trollies were connected at the top by inside angle-irons and box plates, and at the bottom by similar angle-irons and cross plates to impart stiffness. The bearing of the 5-inch axles of the cast-iron wheels in the side beams of the trollies was $4\frac{3}{4}$ inches broad, and special provision was made for lubrication during protrusion and launching. The side plates of all the trolly beams were double, with solid forged bushes or rings riveted between them at all pin-holes. The top and bottom members of these beams consisted of a sufficient thickness of 5-inch flat-iron bars on edge riveted between the side plates. It will be seen that by this arrangement an equal share of the weight was, under all circumstances, transmitted to each of the four cast-iron wheels, and the total weight of the girder ends was equally distributed over 22 feet of viaduct instead of over 7 feet only, as would have been the case had the pendulum links been used as originally intended. The two trollies as constructed weighed, with the cast-iron wheels complete, 38 tons the pair.

The trollies having been inserted at the rear ends, the main girders were lifted at the outer end for removal of the camber blocks, and for transferring their weight to the roller-bearing at point J. This was effected by hydraulic jacks operating under the step or rebate at the outer ends of the girders. The girders, then supported only on the trollies at the rear and the roller-bearings, were ready to be protruded or pushed forward about 2 feet beyond the centre of the bed-plates, and the ends of the girders projected 51 feet clear outside the abutment. The motive power for protruding and launching the main girders consisted—1st, of two three-fold 1-inch chain tackles, each having fixed double sheaves at the abutments, with a single sheave attached to the bottom of the cross girder at the rear end of the main girders, the chains lying on the viaduct beneath the girder platform. The hauling part of the chain

tackles was taken to the rear of the main girders and worked by four-fold 4½-inch Manila rope tackles, hauled upon by horizontal capstans driven through rope gearing by two powerful semi-portable engines (Fig. 1). 2nd, of three 4-inch steel wire-ropes rove through three vertical sheaves, 28 inches in diameter, fixed to the Z irons at the outer or cantilever end of the girder platform. This gave six parts of wire-rope spanning the space between the ends of the main girders and the cantilever, and hauled in by an equal number of five-fold 6-inch Manila rope tackles, extending the length of the cantilever, and worked by the capstans or turks-heads of three steam-winches at the further end of the cantilever, supplied with steam by a 20-HP. semi-portable boiler. When hauling on all six parts of the wire-ropes, the sheaves at the ends of the main girders did not revolve; but, in case of any obstruction impeding the movement of the girders, it was possible to double the strain on the wire-ropes by making one end fast to the cantilever and hauling on the other end by the two rope tackles. In such a considerable operation as moving the 1,000-ton girders with the weight concentrated on two points at a considerable elevation, it was deemed prudent to provide an ample reserve of power; however, it was not necessary to have recourse to the double purchase on the wire-ropes; indeed, the viaduct chain-tackles proved almost sufficient to move the girders with occasional assistance from the wire-ropes. The small amount of frictional resistance developed in moving the girders was no doubt due to the careful manner in which all the preparations and appliances were executed. The protrusion of the girders 75 feet, to place them in position for the final operation of launching or floating across the space to be spanned, was a slow operation owing to the care necessary to keep the 3¾-inch bar-iron rollers square; in other respects no difficulty was experienced. The bar-iron rollers were all turned exactly to the same diameter, but occasionally one or two would get slack or out of square, owing possibly to inequalities in the road.

For floating the forward ends of the main girders and depositing them in position on the recessed benches at the ends of the cantilevers, the pontoons provided for sinking the caissons were used. The central platform, the overhead girders of the rail staging, and the overhanging and central portions of the main trusses, as also the central portions of the auxiliary trusses, were removed, and the pontoons were brought together so that the distance from centre to centre was 27 feet, which is the longitudinal distance between the points H and I in the over-

hanging portions of the main girders at which it was intended to take their weight (Plate 1, Fig. 6). It was necessary to support the girders at two points some distance apart, as a base to ensure the stability of the pontoons, which were placed transversely to the main girders. In this position the pontoons were firmly and rigidly connected together by the main trusses of the rail staging and auxiliary trusses. To carry the girders, a combined timber- and rail-staging was erected over the central longitudinal bulkhead of each pontoon; this consisted of double uprights under each main girder with two pairs of raking supports to distribute the weight fore and aft. The uprights and raking supports were connected at the top and at the summit of the lower rakers by horizontal timbers, and thereby the pontoons with staging combined formed floating trusses, the portions of the pontoons between the bases of the raking struts being subjected to a tensile-strain. Each pair of uprights and rakers was stiffened by old double-headed rails partially let into the outsides of the timbers, and each pair of timbers was connected by distance-pieces and through-bolts. The timbers being in compression, simple butt-joints were used, the rails imparting the necessary stiffness. The staging on the two pontoons was connected by cross timbers and rails at the top and intermediately at a lower level, and stayed transversely by diagonal timbers and external raking supports. The entire structure was firmly bolted and clamped together, and secured to the pontoon decks by bolts and strap bolts. Inside the pontoons the deck was supported and strengthened under the vertical and raking timbers of the superior main staging by longitudinal horizontal sills, with transverse inclined strutting, thus distributing the load laterally over the floor of the pontoons. Advantage was also taken of the rail staging originally provided for the erection and sinking of the caissons, and by which the pontoons were connected transversely, to distribute a portion of the weight to the sides of the pontoons on which the upright supports of the main trusses of this staging were carried (Figs. 5 and 6). This was effected by means of the projecting ends of the top sills of the timber staging, transferring the weight by struts and chains to the overhead girders of the rail staging, the ends of the top sills of the timber staging being trussed by four 5-inch by 1-inch bar-irons passing under the lower cross-connecting timbers, and tightly strained by powerful iron wedges. In this way the original rail staging, made for the erection of the caissons, was incorporated with the timber staging specially provided for carrying the main girders, thereby impart-

ing additional stiffness and stability, and assisting to distribute the load on the pontoons, a most important matter, considering their light construction and the concentrated load to be carried.

The height of the special staging for carrying the ends of the girders was regulated by the tides, the object being to secure the longest time available on a single tide for launching the girders, in case of the operation being delayed or impeded by any unforeseen circumstance, or obstruction, a contingency, however, which did not arise. At the site of the bridge, the height of the tide depends greatly on the quantity of land water in the river, and cannot be foretold with any degree of certainty; however, judging by the records of previous years, it was assumed that on or about the 8th to the 10th of November, 1886, the intended date of launching the first or Hooghly main span, low-water would not exceed 5 feet above datum; the under side of the main girders as protruded was 54·33 feet above datum, the staging on the pontoons was, therefore, made 48 feet 9 inches above water-level at the light draught, leaving a vertical space of 7 inches to be made good by movable packings. The girders of the Hooghly main span were launched on the 8th of November, 1886, when the actual level of low-water was 4 feet 11 inches above datum. The girders of the Naihati span were launched in December, when the tides were considerably lower, involving a greater thickness of movable packings on the pontoon staging. At points H and I, where the girders were supported by the staging, the rivet heads are not countersunk, and hard-wood packings were fitted to the under side of the main girders to cover the rivet heads at these points. The packing at H was made thicker than that at I, so that the outer pontoon began to take the weight before the inner pontoon, the object being that at high-water, when the forward ends of the main girders were considerably higher than the rear ends, the load on the inner pontoon should not be excessive. The draught of water of the pontoons with staging, &c., complete was $2\frac{1}{2}$ feet. To secure the depth of $1\frac{1}{2}$ foot below datum it was necessary to float the pontoons close to the abutments at the lowest tides that might occur on the dates fixed for launching, and the river-bed was deepened by dredging near the abutments. The additional immersion of the pontoons caused by the weight of the forward ends of the main girders was 2 feet, making the total draught of water 4 feet 6 inches. To keep the forward ends of the girders in line during launching, three barges were moored about 200 yards above the bridge, and three the same distance below the bridge. The line of girders was adjusted by

warps from these barges, which were taken to pontoon capstans, and hauled in or slackened as required. The warps were double, passing through sheaves fixed to barges, and the standing part was made fast to the pontoon bollards. The object of this was to ensure sufficient strength in case, as was possible, a breeze from north or south might be blowing on the date of launching, which would tend to cause the girders to oscillate laterally and strain the rear launching trollies. Every contingency having, as far as possible, been provided for, the girders of the main side spans were successfully placed in position, with their forward ends resting on the cantilevers, on the dates shown in the following Table :—

1886.	Low-Water.		High-Water.		Pontoons hauled under girders.	Launching.		Pontoons removed.
	Time.	Level.	Time.	Level.		Started.	Finished.	
	A.M.	Ft. ins.	P.M.	Ft. ins.	A.M.	P.M.	P.M.	P.M.
November 8	10 0	4 11	2 20	9 6	9 0	12 30	2 0	8 0
	A.M.		A.M.		A.M.	A.M.	A.M.	P.M.
December 20	7 0	1 3	11 30	5 9	6 0	8 30	10 30	4 15

After the main girders were placed in position, it was necessary to remove the launching trollies from the rear ends, and transfer the ends of the girders to the pendulum suspension links. This was effected by 100-ton jacks, assisted by specially-constructed rail-levers, as two jacks were not powerful enough to raise the end of one girder weighing 250 tons. To remove the trollies, the jacks were placed directly under the projecting ends of the 7-inch pins at the after ends of the main beams of the trollies; by lifting these pins about 3 inches, the girder ends were raised half that amount, and hard-wood packings were inserted beneath the vertical side plates of the end boxes; these packings were armed with 5-inch by 1-inch bar-irons on the top to facilitate the sliding of the girder ends under variations of temperature. The after ends of the trollies being then lowered, the 15-inch pins were removed from the semi-circular bearings at the ends of the girders, and the trollies hauled back clear of the girders. The transverse diaphragms, temporarily removed from the end boxes of the girders to make room for the trollies, were replaced and riveted; the weight of the girders was then taken at a point near the first cross girder on a platform of rails bedded in Portland cement outside, and clear of the cast-iron bed-plates, by the 100-ton jacks, assisted by rail-levers; and the packings under the sides of the end boxes having been removed, the saddle castings with pendulum

links were slid into place on the bed-plates, and the 15-inch pins having been inserted through the holes in the lower ends of the links, the semi-circular bearings of the ends of the girders were lowered on to them, and the saddle castings finally bolted down to the bed-plates of the abutments. These operations required the provision of special appliances, and to be very carefully conducted in accordance with a preconcerted programme, owing to the great weight to be handled on a confined space. The suspension of the ends of the girders of the Naihati main span to the expansion links, on the 22nd of December, 1886, practically completed the bridge, excepting a few minor details, cleaning, painting, &c.

The difference in the length of the superstructure of the bridge between 40°, the lowest temperature in the cold season, and 140°, the maximum temperature in the sun in the hot season, allowing for portions of the girders not being exposed to the sun's rays, may amount to 6 inches; the bridge being fixed in the centre, this is equal to 3 inches at each end. To provide for this, the joints of about a dozen 23-foot rails, adjacent to the bridge at each end, have a play of $\frac{1}{2}$ inch each, and the fish-bolts are regulated to admit of the rails travelling to that extent. The daily expansion and contraction due to variations of temperature do not exceed $1\frac{1}{2}$ inch at each end of the bridge.

The bridge was tested by two trains, each of thirty-six loaded ballast-trucks, averaging 0·85 ton per lineal foot, hauled by locomotives weighing 74 tons each. With the trains running in the same and in opposite directions, on the up and down lines, the maximum deflection at the extremities of the cantilever was 2 inches, and the maximum depression at the centre of the main girders of the side spans was 3 inches. With the test-train running on one line only, the top booms of the main girders of the side spans showed a maximum lateral deflection of $\frac{5}{8}$ inch at the centre. The lateral oscillation of the bottom booms of the cantilevers and main girders was practically nil.

The cost of the bridge, including the approach viaducts, was £261,178.

Land for the works was acquired, cleared and fenced, and workshops, tramways, jetties, staff quarters, workmen's huts, &c., were built in 1882–83; the material for the pontoons, steam-tender, anchor-barge, moorings, tools and plant, and the caisson materials were received from England in 1883, and the putting together of the caisson rings was commenced in that year; but the actual bridge construction was begun with the launch of the first caisson on the 2nd of March, 1884, and completed with the suspension of

the girders of the Naihati main span to the saddle castings on the 22nd of December, 1886.

It is not easy briefly to describe in a lucid manner the special plant and appliances required, and the operations involved in such a work as the subject of this Paper, and many interesting particulars have had to be omitted. It is, however, hoped that, by the assistance of the drawings and diagrams, the Paper will convey a fair understanding of the nature of the work to be done, and of the means adopted for its execution.

In conclusion, it may fittingly be recorded that it is impossible to speak too highly of the creditable interest which all the staff took in ensuring that degree of perfection and accuracy of workmanship, in every detail, which contributed so much to the successful completion of the bridge.

The Paper is accompanied by a series of small-scale drawings, from which Plate 1 has been compiled.

[Discussion.

Discussion.

Mr. G. B. Bruce, President, remarked that the present was not Mr. Bruce.
he first Paper which Sir Bradford Leslie had brought before the nstitution. All the Papers by the same Author had been marked y great originality in the arrangements by which he had carried ut his work—originality not sought after for the sake of being riginal, but in order that he might be able to carry out the work ssigned to him in the best possible manner. That was also the eature of the present Paper, for which the Author deserved the est thanks of the Institution.

Mr. Ewing Matheson said that while admiring the very ingenious Mr. Matheson.
nd successful manner in which the Author had erected the Hooghly Bridge, he should be glad to know if any alternative proposition ad been considered before he had adopted the method described n the Paper. As the drawing exhibited by the Author did not nclude a plan, it was impossible to tell the width of the pproaches, and it would be interesting to know whether the nassive abutments were necessary to resist the scouring of the iver, or whether they were only put down as part of the viaduct o support the railway and form one pier of the bridge. He wished to know whether, instead of these abutments, piers similar o those in the middle of the channel might not have been constructed by sinking caissons in the manner described, with, of course, the great advantage of having dry land to work upon. That also raised the question whether, instead of the approach viaduct, a shore span might not have been constructed. That was, to a large extent, a matter of cost, on which it was difficult to offer an opinion, but it would be interesting to know whether such figures had been compared. If shore spans had been used instead of the viaduct (which seemed somewhat expensive with its numerous piers and bracing), then came the question whether the shore spans would not also have served as stagings for the girders to have been hauled forward upon. He supposed that they would not weigh more than the viaduct would have to carry for a double line of railway. There was also the further question whether the girders, instead of being hauled forward with such a large span as a heel or balance, could not have been built forward in panels as was usual in America. He did not suggest that the plan adopted was not the best, but should be glad to know how far the other means to which he had referred had been considered.

Mr. Shelford. Mr. W. SHELFORD observed, that there could be no doubt that the erection of the Hooghly Bridge was in itself a very important undertaking; and even those who had had comparatively little experience in such matters could appreciate the work, because they knew it required a great deal of foresight, care, and planning of details, and also involved considerable anxiety of mind until it was actually accomplished. It must be conceded that the launching of a mass of metal, consisting of one complete girder span, weighing 1,000 tons, running upon a line of rails at one end and floating at the other, in a tidal stream where the velocity of the tide was so great, and at times also subject to the greater velocity of fresh water, was a very important and difficult work. There were one or two questions only which he desired to ask the Author. It was stated that "the girders of the main side spans have a deck-plate on the roadway at each end." He presumed that the meaning was that the main side spans had deck-plates at each end, and that the centre was secured by horizontal diagonal bracing in the bottom and also in the top. He should be glad to know what advantages the Author had obtained by the pendulum-link bearing on each abutment, as compared with the ordinary rollers in a frame which had been for years the expansion-joints used in this country. He had seen a similar link bearing on the abutments of the cantilever bridge over the Niagara; but the link, instead of being a pendulum, was under the bearings, and served the threefold purpose of being a bearing when necessary, an anchor when necessary, and also an expansion-joint. He wished also to know whether, after the bridge was erected and the weights were put upon it, the Author had found any tendency to buckle in the central vertical member of the central girder. He observed that it was braced, and he therefore presumed that it did not buckle; but if it did not, it seemed that it must act in compression, and must tend to force down the lower boom of the central girder below the line of compression which it was intended to take. That raised the question of the design of the whole bridge. He did not know that the Author was responsible for it, nor did it appear from the Paper that he was. He understood the bridge to be a continuous girder without continuity; in other words, that the bridge, which on a smaller scale in past times would have been built as a continuous girder, had been erected in the present instance in a more scientific and practical manner; that was, the point of contrary flexure had been fixed and determined, and could not be altered by any loading of the bridge. So far good. Then the girders

of the side spans were parabolic, and were, no doubt, theoretically correct in form. The cantilever, however—perhaps for the sake of symmetry, although he did not quite see it—was also parabolic in form, and he could not think that that was right. Nor did it look right. The pillars, which supported the upper boom immediately over the piers, appeared on the face of the design of the same scantling as the central vertical member to which he had referred, and yet the work to be done by the two was different. The pillars over the central piers obviously had to bear an enormous weight, and he could not help thinking that if the strength that was wanting had not been made up simply by thickness of metal, as it no doubt had been, but had been made evident to the eye, it would have been better, and it would have been better had the piers, in design at all events, been continued, as it were, through the girder, and had terminated in something ornamental. Then, if the upper boom instead of being convex had been straight or with a slight inverse curvature between the piers, and if the upper member on each side of the central piers had also been straight or with a similar inverse curvature, he thought the bridge would have been more perfect, and would have looked better; and he thought it would not have cost more. Mr. Shelford.

Mr. E. H. CARBUTT said that, having taken great interest in Indian railways, he had listened to the Paper with much pleasure. As a mechanical engineer, he felt assured that the Author had taken advantage of every possible mechanical appliance; and when it was remembered that he had to deal not with skilled mechanics, but with labourers whom, probably, he had had to train, it would be admitted that he had executed the work thoroughly well. Considering the difficulty of sinking piers 110 feet deep by 60 or 70 feet broad, in a river 27 or 28 feet deep, subject to the tide and also to the occasional bore, it was evident that the Author had carefully considered everything beforehand. The question had been asked, whether he had considered what would be the effect of erecting the bridge in another manner? On that point the Paper showed, that every contingency that could arise had been taken into consideration, whether in regard to the girders overhanging or putting the girders on the pontoons and strengthening them to resist the strain. He wished to ask if the main girders were suspended only at one end for expansion and were fixed at the other end on the cantilever; if not, what the arrangement was at each end of the cantilever? He should also be glad of an explanation as to the effect of contraction and expansion on the girders, and further to know what arrangements Mr. Carbutt.

Mr. Carbutt. had been made in case the tide fell during the floating of the girder, so that if when it arrived it had been below the cantilever. Perhaps also the Author would state his experience of hanging the girders on levers. He could not help thinking that that was almost a better arrangement for expansion than putting them on rollers.

Sir Juland Danvers. SIR JULAND DANVERS, K.C.S.I., said that not being an engineer he would not presume to criticise the Paper; he would only venture to allude to the moral qualities which had characterized the Author, qualities which were as essential to a great achievement as professional skill and knowledge. He thought that no one could have heard the Paper read, or watched the progress of the work itself, without being struck by the indomitable spirit, perseverance, and pluck which had marked the Author's action during the three or four years that he had been engaged upon the bridge. It might not, perhaps, be generally known that at one time it was doubtful whether he would live to see the work completed. His health had failed from exposure and other causes, and he was obliged to seek another clime, and rest awhile to recruit his strength. He did so, and as soon as his health permitted he went back full of energy to his old love, and to the gratification of all his friends was able to see the operation thoroughly completed under his own superintendence. In listening to the story of the erection of the bridge, it appeared to him that the episode of the escaped caisson added extremely to its interest, showing as it did the extraordinary fertility and resource of the Author during a critical part of the operations.

Mr. Maynard. Mr. H. N. MAYNARD thought that the Author had overcome the difficulty with regard to the foundations in a very admirable and creditable manner. He could, perhaps, best explain his own views by saying that a short time ago he was called upon to examine some bridges on a railway that had been in use for several years, and he found that there was a great deflection in the case of one span. On looking into the matter he found that a tie had been placed instead of a strut in the main girder, and every time a train went over there was an undue amount of deflection, caused by a slight buckling of the tie. He had the tie stiffened, and it became capable of working, as it was called, a brace—capable of bearing tension or compression. In that way the evil was immediately cured. He thought that the amount of deflection mentioned by the Author was a little out of proportion to what had been recorded in the case of other bridges. If that deflection of 3 inches continued with every train that passed over the bridge,

it should direct attention to some means of preventing it, which could, perhaps, be done by a trifling addition. As the deflection of the Britannia Bridge was only about $\frac{3}{4}$ inch in a 450-foot span, 3 inches in a span of about the same dimensions seemed a great deal. Attention might with advantage be drawn to the four diagonal members in that portion of the superstructure situated above or between the central piers, which were shown as ties. They might be stiffened, or a cross-tie might be introduced, which would bring the deflection to what was usual in the case of other bridges. He had been told on good authority that bridges were built which were not deflected more than $\frac{3}{10}$-inch in a span of 450 feet. If the same proportionate deflection existed with other bridges now being built of three or four times the span, it would come to an enormous amount, perhaps 1 foot, which would be a serious thing in the passage of trains. The suspended link was a plan he had adopted many years ago, and it had acted exceedingly well, particularly where the bridges were subjected to wind and storms. In building a bridge in a valley about 1,200 feet wide, he had found that one side of the valley would sometimes be in perfect calm, while the other was exposed to a wind-pressure of 20 lbs. to the square foot. Such changes required not ordinary rollers, but something in the nature of a holdfast. The Author had adopted a very good plan in his sling arrangement. Mr. Maynard.

Mr. W. Martin Wood said that having been in India many years before the Hooghly Bridge was erected, he knew that the question of bridging that river was regarded as very formidable. The work was supposed to be attended with almost insuperable difficulties, both engineering and financial. In 1875 the Author had erected a pontoon bridge with a carriage way, which answered the purpose of making a communication between the two sides of the river, such as had never been obtained before. He should be glad to know if that bridge was superseded by the present one, or if it was still considered worth retaining. He wished also to ask how much higher up the river the railway bridge was than the pontoon bridge. The arrangement adopted in the case of the latter, of having the supports much higher than the pontoons, was very unusual at the time; but he believed that engineers considered it an excellent and ingenious adaptation. In a general point of view no member of the community at Calcutta, whether engineer or not, could fail to appreciate highly the work which the Author had carried out. The junction thereby effected, the East Indian terminus and the railways of Eastern Bengal and Assam, added largely to the efficiency of the whole Indian system. Mr. Wood.

Mr. Wood. It must be very encouraging, especially to the Under Secretary of State and other Indian administrators, to find that the command of mechanical labour in India had so largely increased, as was evident from the successful completion of an enormous work of this kind, where so much dependence had to be placed on native artisans. From recent official correspondence it appeared that the tolls levied on the Howrah Floating Bridge had already sufficed to redeem the debt incurred in its construction; and that the opening of the Jubilee Bridge had not appreciably affected the receipts of the Howrah Bridge.

Mr. Lewis. Mr. W. B. LEWIS observed that the Author dealt with three features of the design, and adduced very strong arguments in their favour; but there were many other points upon which he was silent. For instance, he did not say anything about the appearance of the bridge, and perhaps the universal verdict would be that it was very ugly. He ventured to suggest that if a little more attention had been paid to appearance, the structure would have been a more scientific one than it was now. He had a notion that what satisfied science, generally satisfied the educated eye, and he was afraid that this erection would neither satisfy the educated nor the uneducated eye. Of course that had nothing to do with the gist of the Paper. The three features of design referred to, were the location of the piers in the river, the construction of a viaduct on the lower bank of the river, and the adoption of the cantilever principle at the centre. With regard to the position of the piers, he supposed that no one could give a better opinion on such a subject than the Author, whose former experience on the Eastern Bengal Railway and at the Gorai Bridge, and other large structures, rendered him particularly qualified for judging how such a river should be dealt with. The result had shown that he had combined that happy mixture of boldness and prudence which every engineer aimed at, and had succeeded in fixing the piers in the very best place. With regard to the brick viaduct, without a greater knowledge of the prices of work on the spot than he possessed, it was impossible to enter into any careful calculation; but he had tried to compare it with what had been suggested by Mr. Matheson, namely, making another span instead of putting in the viaduct, and the result was that the viaduct appeared to be far more economical, while it was certainly more substantial, and more convenient in all other respects. He saw no objection to the adoption of the cantilever principle, but, on the contrary, a great many advantages. The reasons assigned in the Paper were very good, and others might be adduced. He

wished to ask, however, why, if the cantilever was the right thing for the centre pier, it was not also suitable for the abutment piers? Also, would not a cantilever placed on the abutment (which was a large structure capable of carrying much more than had been put upon it), extending backwards 90 or 100 feet, have been cheaper, besides narrowing the middle span to some 320 feet, about the length of the Chepstow Bridge, with which the Author had been at one time connected? That was a matter of calculation. What he wished to ask particularly was, why, if a cantilever was adopted for the centre, one was not designed for it, instead of an ugly girder which seemed ill suited to the purpose? Perhaps the Author would also state how the union was effected between the girders and the cantilever, and whether the action of wind upon such a structure had been carefully considered? Roughly speaking, if it was assumed that the surface exposed was about one-fourth of the area, then, with a wind-pressure of 56 lbs. per square foot, which the Wind Commission asserted might be experienced in England, the stress at the joint would be something like 64 tons. If a pressure of 70 lbs. per square foot was reached, it would come up to about 80 tons; and if, as he had seen it stated, the force of gales in India sometimes reached 90 lbs. on the square foot, there would be a stress of 102 tons at that point. The coefficient of friction for metal upon metal was given in the old text books as one-sixth or 0·18. If 500 tons, the half weight of the main girder span, were multiplied by 0·18 the result would be only 90 tons. Doubtless this coefficient was too low, but he wished to know whether that joint was calculated to withstand uninjured the pressure which might come upon it in a cyclone. Such a pressure, of course, would not be merely direct on the cross-girder, but might strike underneath and tend to twist the structure. Mr. Lewis.

Mr. F. WENTWORTH-SHEILDS thought there was no difficulty in answering off-hand the last question, namely, whether it was probable that the wind would shift the joint at the point of contrary flexure, even supposing it was unattached by bolts or girders, and simply held together by the weight of the abutment girder end resting on the cantilever. The weight on the abutment girder end was 500 tons resting upon that point, without running load; and if one-third was taken as friction, evidently that friction must be overcome before the force of the wind could shift that point, as a force of wind equal to 100 tons could not overcome 166 tons of friction. The highest praise that could be given to the Author was that he had adopted a mode of Mr. Wentworth-Sheilds.

Mr. Wentworth-Sheilds.

construction which all engineers should adopt in great works of that class, namely, the one which involved the least risk in the erection of the bridge. The great depth of water underneath precluded the placing scaffolds in the river in the ordinary way; and, in addition, there was an extremely rapid current and a large river traffic. Under those circumstances the operation of carrying the bridge forward, partly by rolling and partly by the pontoons being shifted in a straight line in the direction of the bridge, was the safest and best mode that could be adopted. The shore end of the girder was stable, and the other end floating, and the floating end, having to be carried along in a straight line, was capable of adjustment by warps in a much more complete manner than if the bridge had been erected upon a scaffolding in shallow water, lifted on pontoons, carried bodily, and lowered into its place. The method chosen, under the circumstances of the river, was safer, and the Author was perfectly right in adopting it. That principle was evidently the key to the whole construction, and no doubt it was starting from that point that the Author had schemed the construction of the bridge. There were some points in which he, for one, thoroughly agreed with the Author. He saw no means of improving the construction of the central piers; but he could not equally coincide in all the details of the construction of the girders. The striking point in the design of the bridge was, that the girders really formed a continuous structure 1,200 feet long right across the stream from one abutment to the other; and that, at each point of contrary flexure, the girder was completely cut through. In theory that might be done, but he had never known of its having been done before. He thought that was objectionable, because the possibility of an accident, such as a locomotive running off the line, or the mast of a heavily-laden vessel in a flood, striking with great velocity upon that point, formed an unpleasant feature in the bridge. Such an accident might not only wreck the train, but might wreck the train and bridge together. It was always preferable, in the construction of girder-bridges, to adopt a system of bracing in which the braces should cross one another at frequent intervals, rather than one depending upon single triangulation. In the single-triangulation system, in whatever shape it might be, the injuring or crippling of one brace involved the collapse of the entire structure; whereas, in frequent triangulations with frequent intersections, not only did the braces stiffen and support each other, but an injury to one brace was comparatively little felt, and the bridge was safer in consequence. It had always seemed to him that where the

braces frequently supported and crossed and stiffened each other in this way, the structure was of a higher order and class than a single-triangulation bridge. He agreed with what had been said in regard to the inartistic appearance of the bridge. He should have preferred to put the two piers a little further apart, say 200 feet, leaving a single span of 500 feet on each side, instead of 420 feet. The two piers would then have been connected by a comparatively small parallel girder of 20 feet in depth and 200 feet in length, and each side-girder of 500 feet, with curved top, and depth, say, of 50 feet at the centre, and 20 feet at the ends to correspond with the depth of the central girder between the piers, would, instead of bearing upon the cantilever, have borne directly upon the central piers. He should consider that a safer and preferable mode of construction, as well as of better appearance; but at the same time he was not dogmatic. No doubt the Author was quite as qualified as he was to give an opinion on that point, and it was with the utmost pleasure that he bore testimony to the careful way in which the design appeared to him to have been worked out, and the admirable ingenuity shown in its construction. Mr. Wentworth-Sheilds.

Sir Douglas Fox considered the Paper to be a description chiefly of the mode of putting in the foundations of the bridge, and of fixing the superstructure. As far as he could understand, the Author did not profess to give details of the superstructure itself, which was to be regretted, because no doubt a great deal of interesting discussion would have arisen thereon. It appeared to him, that if this bridge were going to be designed again, and the design was now rather an ancient one, probably neither the design of the superstructure nor the mode of erection adopted would be chosen as the best. In this country, in the notable instance of the Forth Bridge, and also in America, much had been done in the way of fixing cantilever bridges without scaffolding from the piers at either end. That plan had been adopted to a considerable extent both in the United States and on the Canadian Pacific Railway, and great economy had resulted. There might have been other reasons no doubt, besides its use for rolling over the girders, why the heavy viaduct was constructed. It was said that the land was very valuable, and also that there was some necessity for flood waterways; otherwise it did seem that the viaduct was an expensive mode of providing for what was only, after all, a temporary requirement. It had to carry a very heavy load once, and never again, and from that point of view seemed to have been an expensive form of scaffolding. The pontoons also, if they had been required only for floating the girders, would have been costly Sir Douglas Fox.

Douglas x.

expedients. He should much like to see the details of the joint between the cantilever and the main girder of the large span that had been already referred to. He could not himself believe that the design of the cantilever portion of the girders, as generally shown by the diagram, would give as good a result as might have been obtained, if some modification had been made in the arrangement of the diagonals, especially over the piers. The deflection appeared to be considerable, and he believed it could have been reduced if the design had been modified. He was also strongly of opinion that the appearance of structures should receive greater attention from engineers than was frequently the case. In the present instance, the effect produced was unnatural, and therefore unsightly. He should be glad to have information as to the specification under which these large girders had been manufactured, both as regarded the quality of the steel, and the tests applied to it; and should also like to have a little more detail as to the exact behaviour of the cantilevers under variable loading, which would be valuable for many reasons. Turning from the superstructure, which was only touched upon in the Paper, it must be admitted that, given the design, given the position of the piers, and given the viaduct and pontoons, the way in which the work had been carried out was most instructive, most interesting, and most creditable to the Engineer-in-Chief, and to all concerned. He gathered that the work was carried out departmentally, without the intervention of a contractor, and that added greatly to the anxiety and responsibility of the chief Engineer. Only those who had experience of deep foundations, in soft material in a strong current, could fully appreciate the gravity of the task. The account of the pontoons used in sinking the cylinders for the piers; the way in which they were held in check by means of cables and placed exactly in the centre line of the bridge, in spite of the current running sometimes at the rate of $5\frac{1}{4}$ miles an hour, was most interesting; as was also the method by which the cylinders had been successfully sunk into position through soft silt, so soft that it was very difficult to prevent its being washed away outside the cylinders. The Author had described the accident to the pontoon with the utmost frankness. Engineers liked to know the difficulties that had arisen in connection with important works, because it was only by such knowledge that they could provide against them in the future; and to this end the American Society of Civil Engineers had offered a medal amongst other things for descriptions of difficulties which had arisen, and of failures which had occurred. He was sure that all

the members most heartily congratulated the Author that he had been spared to see the completion of this very important work. Sir Douglas Fox.

Mr. M. AM ENDE said he agreed with the remarks of previous speakers upon the general arrangement of the superstructure of the bridge; but as this could be made of sufficient strength and with a fair degree of economy, there was no need to discuss other arrangements. It would be interesting to know whether the coefficient of friction of the earth on the surface of the pier, stated at 5 cwt. per square foot, was derived from experiment. Friction was relied upon almost entirely in pile foundations, and there was no reason why it should not be taken into account in caisson foundations, provided that it could be ascertained; and this might be done without much difficulty while the boring trials were made. In the erection of the two side girders, the process of rolling them upon a set of small rollers, which seemed to have given some trouble, might, he thought, have been avoided, if the girders had been put together directly in a more forward position, with one end overhanging; the only reason why this was not done seemed to him to be that the diagonals were not designed to bear the strains contrary to those which they had to bear in their final position, a provision which, however, might easily have been made. The girder itself seemed to have a weak point at the springing of the curve. If a line were drawn from the pin to the intersection of the first diagonal with the neutral fibre of the curved flange, that line ought to coincide with the neutral fibre of the section along that distance; it was not necessary that this line should be straight, but instead of a single diagonal, there should then have been a fan of diagonals. If flanges of girders had to be curved, either sharply or gradually, the whole strain ought to be transmitted through their vertical plate at the bend, and very often no notice was taken of this. Parts laterally projecting beyond the web, like angle-irons and flange-plates, had bending-strains as well as compressive or tensile-strains where the bend occurred, and the former were generally very great. Let s_b be the additional bending-strain, s_c the compressive-strain, h the free projection, t the thickness of the projecting rectangular part, r the radius of curvature in inches, then Mr. am Ende.

$$s_b = \frac{3\,h^2}{t}\,\frac{s_c}{r}.$$

In an angle-iron, 3 inches by 3 inches by $\frac{3}{8}$ inch, the additional strain would be $s_b = 72\,\frac{s_c}{r}$, and, therefore, the total strain would

Mr. am Ende. be double the compressive-strain, even with so large a radius as 72 inches. It would be seen, therefore, of how little value the metal of laterally projecting parts was in bends. Mr. Maynard seemed to think that if one of two girders, of equal length and of equal strain per square inch, was deflected more than the other, it ought to be strengthened regardless of the cause of the greater deflection. This could hardly be his real meaning. The larger deflection of a girder, corresponding to a smaller depth, so far as it did not include a permanent set, was in itself not injurious if in the construction of the girder regard had been had to a certain increase of the moving load due to that deflection. This increase took place mainly in two ways. Firstly, by the quickness of the moving load coming on the bridge. If it came quite suddenly, it was known that the deflection, and consequently the strain, was double what it would be if it came there slowly. In the former case, the time during which the deflection was completed was—

$$T = \frac{\pi}{2}\sqrt{\frac{\delta}{g}} \text{ seconds,}$$

δ being the deflection, and g the acceleration of gravity = 32 feet. The deflection of an iron girder of l feet length, and d feet depth, with a strain of s tons per square inch, was approximately

$$\delta = \frac{s}{40,000}\frac{l^2}{d}. \quad \text{If } \frac{l}{d} = 10, \text{ then } T = 0{\cdot}0044\sqrt{s\,l}.$$

Taking $s = 3$, and $l = 100$ feet, the time was 0·074 second, while a railway train would take at least twenty times as long to occupy the bridge. Relatively to the period of the vibrations of the bridge, the train would therefore be almost a quiescent load. That relation, however, was less favourable as the length of the girder decreased; and that might explain the increased deflection which had been noticed by some observers when a small bridge was passed by a train at high speed. Secondly, an increase took place in consequence of the centrifugal force of the load moving in the hollow of a deflecting bridge. This force was $\frac{M v^2}{g r}$, where M was the moving load, v its speed in miles per hour, g the acceleration of gravity in miles per hour, and r the radius of curvature of the deflecting bridge. Introducing $r = \frac{l^2}{8\delta}$ and as before $\delta = \frac{s}{40,000}\frac{l^2}{d}$, so that $r = \frac{5,000\,d}{s}$; further $g = \frac{32 \times 60 \times 60}{5,280} = 21{\cdot}8$,

and $M = ml$, where m = moving load per lineal foot, the centri- Mr. am Ende.
fugal force was $\frac{m v^2 s}{109,000} \frac{l}{d}$.

It was, therefore, independent of the span of the bridge for all bridges of equal proportion of span to depth. Taking this at 10, $m = 1{\cdot}25$ ton, $v = 40$ miles, and $s = 3$ tons, it was—

$$\frac{1{\cdot}25 \times 1,600 \times 3}{109,000} \times 10 = 0{\cdot}55 \text{ ton.}$$

This was a very small additional force in the case of most bridges; but, in very small bridges it might account for an increased deflection, as the sudden approach of the moving load on the bridge, referred to previously, accounted for it. These items should, however, be introduced in the calculation of the strength and the deflection of a bridge when necessary; and if that had been done, and if the actual deflection, no matter how large it might be, agreed with the calculated one, it was a satisfactory state, and not one to be uneasy about. If some engineers said the deflection of a bridge should not be more than $\frac{1}{2000}$ of its span, they appeared to have in their mind a proportion $\frac{l}{d} = 10$, and a strain by the moving load to the extent of 2 tons per square inch, and they forgot that equally good bridges might be constructed where these conditions were different, and the deflection consequently also different in proportion.

Mr. B. BAKER said that the Author knew very well that a good Mr. Baker.
Paper on bridge building by a good man would always be welcome at the Institution, and both those conditions had been complied with in the present case. It would be very singular if it were not so, because Telford, the great president and founder of the Institution, was nothing if not a bridge builder. That being so, it appeared remarkable that it was necessary to go back twenty-seven volumes to find a discussion on bridge building, and then it was raised on a Paper by a distinguished Frenchman. A second discussion would be found thirty-six volumes back, and then the Paper was by a distinguished American; and going back fifty-six volumes, considerably more than half of the publications of the Institution, there occurred only six or seven discussions, including the present one, and if the present one was included it was rather noteworthy that two out of those were Papers by members not belonging to this country, and three were raised on Papers by the Author, leaving very little for home engineers to do. If he trespassed therefore beyond the bare limits of the Paper, his excuse must be the very few opportunities there had been of saying any-

Mr. Baker. thing at all about bridge building in recent years at the Institution. It might be interesting if he communicated the contents of a letter which he had just received from the Engineer-in-Chief of the Roumanian railways, with reference to a bridge about to be built across the Danube 180 miles above Sulina; because singularly enough he was working out a problem there very similar to the Author's, but in a modified form. The bridge referred to included one span of 610 feet, two spans of 500 feet, and two end spans of 433 feet. The latter, as in the Hooghly Bridge, were made up of a girder with curved top boom and a cantilever, but the curve of the cantilever was concave instead of convex, as was also the curve of the girder between the two piers. The result was that the structure looked more like a true cantilever bridge than did the Hooghly Bridge, and the nature of the stresses was better indicated. The design seemed very similar to that suggested by Mr. Shelford. There was another point with reference to appearance he might touch upon, namely, that the struts of the Hooghly Bridge looked very much lighter than the ties. Speaking from the appearance of the Forth Bridge, so far as it had been constructed, whether looked at from 100 yards off or from 20 miles, the fact of having the compression members apparently solid, 12-foot tubes instead of light lattice work, gave a very satisfactory appearance of security to the eye. He did not like the struts looking lighter than the ties; it might be partly because he was familiar with American bridges, where the reverse would be the case. The ties in an American bridge would be about 8 inches wide, or about one-quarter of the width of those of the Hooghly Bridge, and that would give an entirely different appearance to the structure. The cylindrical struts at the Forth Bridge, although they had such a very comfortable appearance, really meant very little additional cost; probably about 6 per cent. of the total cost per ton of the erected steelwork would cover the difference between the tubular and lattice members, and against that there was of course the metal doing its work more efficiently in the tubes. The general design of the Jubilee bridge, it appeared to him, had hinged almost wholly upon the conditions of the piers. The Author had described how he founded those piers by means of pontoons, and having those pontoons it would seem that he thought he might use them for the erection of the bridge. If he had been sinking caissons without the aid of pontoons, it was to be doubted whether he would have adopted that design of bridge, because of course the pontoons would be very expensive if used only for the erection of the girders, and probably their

cost would have been avoided by a modified design and mode of erection. At the Forth Bridge, and in many other cases, of course caissons were sunk without pontoons. A very interesting bridge was now approaching completion in America—the cantilever bridge across the Hudson at Poughkeepsie. The caissons had some points of novelty, which were arranged by the engineers and contractors, Mr. T. C. Clarke, M. Inst. C.E., and his partners, in consultation with himself. The conditions were foundations about 130 feet below water, and about half of that depth was mud. The rail-level was 212 feet above water, and there were five spans about the same as in the Hooghly Bridge, namely, from 525 feet to 548 feet in width. The largest caisson was 100 feet long by 60 feet wide at the base, and 115 feet high from the cutting edge to the top. In plan it was divided into forty cells extending the full height, and varying in size from 12 feet square to 6 feet square. The exterior and the partition-walls of these cells consisted of double baulks of timber securely fastened together. To weight the caisson, gravel was filled in the exterior line of cells and some of the interior ones, and to sink the caisson dredging was carried on in the other cells. Of course these caissons being of timber could easily be floated out and moored in position, and if the caisson was tipping on one side the dredgers could easily be set at work to remove some of the gravel. All the caissons were sunk down without trouble. The erection of the Poughkeepsie Bridge was being proceeded with very rapidly and successfully, and there was one point about it that he wished to refer to. The intermediate spans of 525 feet between the cantilevers had to be erected on staging. There was here a very good opportunity to compare the relative cost of erecting bridges of the same span on staging, and by overhang on the cantilever plan, and he had a letter from Mr. Clarke stating the result. It came to this in effect, that the cost of the staging for the independent span was more than the whole cost of the steel plates and bars required for the cantilever. It was no good merely to compare the weights of independent and cantilever girders, but what it cost to erect them must be considered. It cost no more to erect a cantilever span by overhang than to erect the independent span after the staging was provided. That was a very interesting, practical fact arrived at by Mr. Clarke, because this Poughkeepsie Bridge was on a very large scale. Applying this experience to the Hooghly Bridge, it led him to think that if the caissons had been sunk without pontoons, the Author would not have had so long a brick viaduct, but would

Mr. Baker.

Mr. Baker. have built a true cantilever bridge, with shore cantilevers as well as central ones, and have erected it by overhang without staging or pontoons. He might have done it certainly for the same weight of metal, because, comparing it with the Niagara cantilever bridge, 910 feet over all, and with a weight of 1,520 tons, two such cantilever bridges would just about cross the Hooghly, and that would be 3,040 tons. The weight given in the Paper was 3,676 tons, so that there would have been about 600 tons to spare for the difference between the English and the American type of bridge construction and the slightly greater span. Of course, there were unavoidable risks in floating out girders, and he could easily understand that it was a very anxious time when the bridge was in the condition shown in the Author's diagram. The cantilever construction was safe at all stages: there was not the least difficulty in overhanging, and, in fact, the men rather liked the novelty. At the Forth Bridge the difficulty was to make the men realize the height they were at, and the inevitable consequence of a stumble. He saw a man not long ago doing what was equivalent to dancing a jig on a saddle rubbed all over with linseed oil, 360 feet up in the air. There he was, with his hands in his pocket, dancing away, not out of bravado, but simply to keep himself warm. Besides receiving the letter from Roumania, to which he had referred, and which, curiously enough, illustrated some of the points in discussion; he had also on the same day received a letter from Mr. T. E. Harrison, Past-President Inst. C.E., of the North-Eastern Railway, unconsciously illustrating another point in the Paper. He had been discussing with him some of the arrangements for expansion and contraction which had been made at the Forth Bridge, and Mr. Harrison in his letter said, "There is nothing new under the sun. I send you tracing of expansion motion for a bridge at Hull. I do not know who put it up, but it must be forty years old, and probably it was the late James Walker." The tracing showed that the bridge was 144 feet span. It had lattice-girders, supported at the ends by a shaft 7 inches in diameter, carried on a cast-iron bracket on each side; and between the cast-iron bracket and the girder were a couple of wrought-iron links, which came down and went flat under the girder, so that, when the girders expanded, the links rocked exactly as in the Hooghly Bridge. He was sure the Author would be glad to hear, on the authority of Mr. Harrison, that the pendulum-link system had worked well for at least forty years. The expansion between the centre piers, the Author stated, had been arranged for by taking advantage of the elasticity of

the piers. At the Forth Bridge that was a question which caused a good deal of consideration. In the original design, by Sir John Fowler and himself, the difficulty was evaded by not carrying the steelwork across the space between the double piers at Inchgarvie, but substituting a heavy granite arch to take up the thrust, while there were single piers instead of double ones at Fife and Queensferry. Of course, a man convinced against his will was of the same opinion still; and he was of opinion still that that was the right way of doing it. However, more potent authorities than himself thought otherwise, and so the steelwork had been made continuous, and expansion had to be provided for. Rollers were absolutely out of the question, because the expansion and elastic deformation took place in every direction—not only longitudinally, but crossways and radially—so that if rollers had been put, or anything like them, they would have been simply tied up into knots in the course of six months. What was done was to make the piers very strong, and rest the superstructure on sliding bed-plates properly lubricated. Experiments were previously made with plates of steel, lubricated with crude petroleum, and moved about by machinery as much as it was thought the bridge would move in five hundred years. The surfaces were then examined, and found uninjured, and so sliding bed-plates were adopted, and the steel superstructure and the granite piers were left. One point, which was really not very important in this particular case of the Hooghly Bridge, might be important in other cases, and therefore he would refer to it. The pendulum links were placed on the abutments. That was wrong, in a certain sense, and would be dangerous in some cases, for this reason, that any end stress on the bridge, such as occurred in the present day when continuous brakes were used, would all take effect on the centre pier, and would put a heavy bending-stress on the iron columns; whereas, if the suspension-links had been put at the end of the cantilever and the main girder fixed to the abutment, a far greater proportion of that end thrust would have been transmitted at once to the abutment without putting any bending-stress on the centre-piers. Longitudinal stress from brakes was an extremely important element in the design of viaducts at the present day. Last autumn some experiments were made on the West Shore Railroad with the Westinghouse brake, fitted to a train of American box-cars, each weighing 20 American tons light, and 50 tons loaded, with a length of 38 feet 4 inches. That came to very much the same as a continuous string of locomotives, and the experimental

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Mr. Baker. train consisted of fifty of those cars. It would take only thirty cars to cover the whole of the Hooghly Bridge. From the rate at which the train pulled up when the brake was applied, it might be at once deduced that the retarding force must have been one-seventh of the weight. That would mean, that a similar train coming over the Hooghly Bridge with the brakes on would produce a longitudinal shove of 200 tons. Now 200 tons acting at the top of those piers 33 feet high, meant a bending moment of 6,600 tons. In this case the piers were very strong, and he did not suppose that bending moment would do more than increase the stress on the iron perhaps 40 per cent., but in many cases it would be sufficient to bring the bridge down. There was no doubt at all about it. Take a case, for instance, like the old Tay Bridge, in which there were five continuous spans of over 200 feet fixed only at one pier and on rollers at all the others, and imagine a train crossing and putting on its continuous brakes; since even in the old days the passenger trains then running had a retarding force of 20 tons, there would be a force of 20 tons acting longitudinally, which was probably more than the effective strength of the pier in that direction. Apart from strength, the piers were so flexible that if the longitudinal shove had been much less than 20 tons it would have simply lurched the superstructure forward, and taken the end girder off the rollers, and let it drop down into the sea, if it had not been held up by the permanent way. Sir Thomas Bouch, with practical instinct, did not put expansion-joints in the permanent way as in the girders, although, perhaps, he was thought rather foolish for not having done so: but if that had been done, the Tay Bridge might have gone down any fine afternoon, just as well as when a gale of wind was blowing. He ran longitudinals and rails right across the bridge, and bolted them to the girders regardless of expansion, so that the bridge was tied together. Of course the permanent way was not a satisfactory tie, because it expanded and contracted, and it could not both be free to expand and contract and be efficient as a tie between piers 1,000 feet apart; for the intermediate piers with rollers contributed nothing to longitudinal strength. Why he mentioned this was that he did not think it came out at the Tay Bridge inquiry; and yet it was an element of danger which would be quite sufficient in that, and also in other bridges now standing, to be fatal. The heavy side-pressure of wind came to very much the same thing as brakes, because that ground the flanges against the rails, and stopped trains continually. If an engineer were to rely upon the permanent way to hold up

viaducts against longitudinal stress, all his calculations would some day be upset by the platelayers in making renewals, or by loose keys, which he was informed were a special characteristic of the Old Tay Bridge, and decayed sleepers. He was not nervous, and took his chance of breaking his neck with moderate cheerfulness, but if a wave of nervousness ever did come over him, he should certainly ask the Board of Trade to send a circular letter to railway companies, to warn them that, in placing in the hands of engine-drivers powerful air-brakes, they were giving them an agency by which they could, under certain conditions, throw down a viaduct into the valley beneath. It had been said that members of the Institution were always glad to hear particulars of failures. He had often thought it was a pity that there were not supplementary Papers recording experiences in the way of repairs required by works described in the Minutes of Proceedings, so that it might be known, for instance, whether bridges which had been described, and the description repeated in different periodicals, behaved as well as the designers anticipated. Curiously enough it had fallen to his lot to examine professionally three of the principal and most typical bridges built by Telford, and in each case the bridge had exhibited defects. One was the Suspension Bridge over the Menai Straits. He asked, in the first instance, to see the drawings, because he wished to ascertain if he could detect where the bridge would be likely to fail. Of course it was easy to do that now, but it was difficult for Telford to do so sixty or seventy years ago. On examining the drawings he noticed two weak points, one being in the floor bearers. Telford assumed that the whole bridge would undulate perfectly together, but if that was not the case, and if one chain tended to undulate a little bit more, so as to produce a vertical oscillation, the floor bearers must break from "fatigue." He went below on the hanging stage, and saw that these floor bearers had all broken across, and had been patched by links, giving freedom of motion in that direction. Another point was the anchorage plates, which might be seen depicted in engineering Encyclopædias over and over again. He thought there was a weakness there, and examined seven anchorages, but did not find any fracture; but on coming to the eighth he found it was broken at the place indicated by theoretical considerations. That sort of fact would be interesting if placed on record, because at present all published descriptions would lead to the belief that the bridge, as designed, stood perfectly well. He was glad to have been able to advise H.M. Office of Works that Telford's great bridge was in all vital

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Mr. Baker. respects as sound as it was sixty-two years ago, although, by an alteration in the floor, the stress on the chains had been increased from 5·8 to 7·35 tons per square inch. The next was the fine masonry bridge, of 150-foot span, across the Severn at Gloucester. The abutments had gradually gone over, and had been continuing to go over for sixty years. The result was that certain barbarians were actually urging the magistrates to take down the bridge, because the soffit of the arch had got a reverse curvature. It certainly looked rather like tumbling down, and the cracks in the spandrels were big enough to walk through quite comfortably. He told the magistrates it would be a disgrace to the country if they pulled down Telford's historical work and substituted a hideous iron lattice-bridge. It had failed because the wing-walls had been built (and many failures had since occurred from the same thing) on what Telford mistook for clay, whereas it was really indurated mud, and underneath that was peat. Mr. Baker tried to get down and underpin the wing-wall to solid ground, but came to water, and stopped, as pumping would certainly have brought down the bridge. What he then did was simply to build on the bad ground, underpinning as deep as he could and as wide as he could to reduce the load per square foot on the foundation. He suggested that the cracks should be left for eighteen months, and then cut out and rebuilt. He was glad to say that the measures adopted seven years ago had stopped the whole of the movement, and he saw no reason why that bridge should not remain perfectly satisfactory to all time. The third bridge was the very interesting cast-iron arched-bridge near Colebrookdale, which he went to see on behalf of the Shropshire Magistrates in the hot days of last summer. It was a combination of arches, a high arch on each side and a flat arch at the centre. They had been patching that bridge for the last ninety years, from the first five years after it was built, because the high arch and the low arch would not work together. The strongest arch was of course the flat one, because it was made of continuous, solid plates extending right across the width of the bridge, whilst the high arch consisted merely of a couple of facial ribs. Expansion and contraction broke the high arch and the connections between the arches. Wherever it broke they put all hands to work and fished it. Then either the bolts sheared or the ironwork broke in another place, and so on. The authorities doubted the safety of the bridge, and there was a talk of re-building, but his report was:—"Leave the unfortunate bridge alone: that is all it wants you to do. There is nothing unsafe about the bridge. It is perfectly strong, and the stress on the iron is in all

vital parts very moderate. The high arch is not essential to stability, but neither is it useless, for under the passage of a rolling load it has a different rate of vibration to the flat arch, and has a stiffening effect. All you have to do is simply to fish these fractured ribs, and put oval holes in the fishes, and not screw up the bolts too tight." There would be no more trouble about it. He mentioned these three cases of Telford's bridges because, as had been already said, it was most valuable to have records of defects. He did not remember any publication in which information had been given about the trouble there had been with these bridges, and, therefore, students who knew nothing more about it might have imitated the designs in perfect confidence that structures which had stood from sixty to nearly one hundred years must necessarily be safe models. These examples further showed that the highest practical experience would not avail without sound theoretical knowledge. No engineer need hesitate to contribute to the record of defects in structures, for, as Professor Huxley had well said, the very superior people who never made mistakes always turned out on investigation to be just those who sat still and did nothing. Mr. Baker.

Mr. J. Wolfe Barry said he should like to know from the Author the reasons, which he was sure must be good ones, for having adopted the cantilever mode of constructing the bridge. The Paper, however, was not on the bridge itself, but on the erection of the bridge, and he would ask the Author to state what was the total range of the tide at the spot, and also what was the difference of level during the time taken in launching the girders on pontoons. The time recorded he believed was one and a half hour in the one case, and two hours in the other; during that time there was of course some movement of the water, which might have been considerably larger if the time had been extended. Another question he should like to ask was on the subject of the abutment on the right-hand side of Plate 1, Fig. 1. It was evident that that abutment had been placed considerably higher than the bottom of the river, in a not very remote position from it. Perhaps in the annals of the Hooghly that particular part of the river bank was not subject to alteration; but at first sight the level of the foundations looked a little dangerous. A question had been raised as to the relative cost of construction of a bridge built in the way which had been adopted, and of bridges built in other ways. All he could say was that, without going into comparisons, he greatly admired the extreme ingenuity and foresight and the economy both in the erection and in the construction of this large Mr. Barry.

Mr. Barry. bridge. The total cost compared favourably with that of other bridges of anything like the same length and span, and in all probability it would appear that the saving realized by the mode of erection had amply justified any possible excess of iron in some parts of the structure. Although he did not admire the junction between the girder and the cantilever, he thought that in these structures of magnitude engineers should look to what was cheapest, provided that it would do the work in a really efficient way, as it was a mistake to sacrifice a large sum of money for any fancied improvement of an unessential nature. Critics soon became accustomed to different forms of construction; and, when they realized the fitness of such forms of construction, they would not perhaps blame engineers for adopting forms of bridges, or of any other structure, which at first sight perhaps ran counter to some principles of beauty to which they had been accustomed.

Mr. Waring. Mr. F. J. WARING, having himself had experience in bridge construction in Indian rivers, expressed his most cordial concurrence as to the soundness of the reasons which led the Author to place the piers where he did. The Paper would have been more valuable had some details of the superstructure been given. It was, perhaps, too much to ask for these now; but, the girders being of steel, if the Author would give the extreme tensile and compressive-stresses allowed in their various members, it would make the Paper still more interesting. Some remarks had been made upon the deflection of the main girders. It was stated in the Paper to be 3 inches, which was $\frac{1}{1,680}$ part of the span, and in various bridges with the construction of which he had been connected an allowance of about $\frac{1}{2,000}$ of the span under the test loads had been the rule, though he was told that American Engineers went to $\frac{1}{1,200}$, and that in English practice the deflection might vary between $\frac{1}{1,600}$ and $\frac{1}{2,400}$ of the span. The total length of the Hooghly Bridge was 4,930 feet, including the approaches, and, calculating the cost, it came to £53 per lineal foot, a result that must be deemed most satisfactory, looking at the magnitude of the structure. It certainly compared very favourably with the cost of the Gorai Bridge, which, after crediting it with everything, came to £95 per lineal foot.[1] The superstructure of the Gorai Bridge was for a single line, while that of the Jubilee Bridge was for a double line, which would make the comparison still more favourable for the latter. When the Gorai Bridge was constructed no

[1] Minutes of Proceedings Inst. C.E. vol. xxxiv. p. 41.

doubt the price of material was higher than when this bridge was built, and therefore, if some details of the cost of the manufacture of the girders and their freight, and also a brief classified statement of the cost of the bridge had been given, it would have added greatly to the value of the Paper. The absence of the yellow clay at the Naihati abutment rendered it doubtful, in his mind, whether the yellow clay at the Hooghly abutment and piers was not merely a local stratum, possibly of very limited thickness. If that should unfortunately prove to be the case the permanent stability of the bridge would be endangered. Of course borings were taken to ascertain the thickness of this clay, but it would be interesting to know what the thickness was. With regard to the approach viaducts, having had a little experience in engineering work in the neighbourhood of Calcutta, he thought the foundations there were the worst he had ever encountered. The subsoil at a short distance below the surface was little better than silt or quicksand, containing often much water. While the girders were being protruded, half their weight, 500 tons, was carried on trolleys having a wheel-base of 22 feet. The concrete foundation was stated to have an area of 50 square feet per lineal foot of viaduct; and this weight was therefore distributed over 1,100 square feet, which would only be 9 cwt. per square foot, and this he thought must bear a very small proportion to the weight of the brick viaducts themselves. Knowing, as he did, the excessive badness of the foundations near Calcutta, it would be interesting if the Author would state the weight that he thought safe to impose on the foundation per square foot. Mr. Waring.

Sir BRADFORD LESLIE, in reply to the discussion, said his original proposal was to span the river by two arches springing from a central pier. The arches were intended to be constructed of the old iron rails taken out of the railway as the line was relaid with steel. The old rails were worth only 36*s.* a ton at Calcutta, and with the raw material so cheap a very massive bridge could have been erected at a comparatively small outlay, while he was confident that no more stable or durable structure could have been devised. The proposal, however, did not commend itself to the Railway Company's Consulting Engineer, and was abandoned in favour of a more orthodox type of construction. Several other designs were considered, and among them a cantilever supported on the abutment and built forward in panels without staging. Such a cantilever would have required to be anchored in rear of the abutment, thus substituting a shore span for a portion of the brick viaduct; but this would have been Sir Bradford Leslie.

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more expensive than the plan adopted, necessitating a greater quantity of steelwork in the superstructure. The plan of building forward an ordinary girder in panels was not considered. In a deep ravine it might be necessary to have recourse to such an expedient; but, with the river available as a road to carry forward the girders, it appeared to him much more simple to adopt the plan described in the Paper. To build forward a span of anything like 400 feet in panels would have necessitated very heavy tackle for the temporary support of the structure, and a shorter length would have been practically a cantilever, that would have required an intermediate span, say of some 300 feet, to be built on shore at the low level, floated out on pontoons, and hoisted up between the ends of the two cantilevers, the central and the shore cantilevers. Such a design would have been something like that suggested by Mr. W. B. Lewis, consisting apparently of a single pier cantilever on each abutment, with the double pier cantilever in mid-stream, and two intermediate spans of about 300 feet each; the weight of the superstructure would then have been 3,900 tons against 3,465 tons in the superstructure as constructed. Altogether this design appeared more complicated and difficult of erection than the plan adopted. Mr. Matheson suggested the use of a shore span instead of the viaducts, supposing that such a span would have been cheaper than the viaducts. Such a span, if it had been made strong enough to bear the weight of the girders while they were being hauled forward, could not, of course, have been constructed for anything like the price of the viaduct. It was a maxim in India never to use iron or steel where brickwork or masonry would answer the purpose. The double-line brickwork viaducts 40 feet high cost about £40 per lineal foot, and nothing in the shape of a shore span strong enough for the girders to be hauled forward could have been made for the money. Considering the advantage of the solid brick viaducts upon which to erect the girders, and when finished for hauling the latter over to their permanent position in an hour and a half or two hours, there could be no question as to the preference of the design adopted over any other considered in the first instance, or which had subsequently been suggested. The dead weight and live load on each abutment was not less than 1,000 tons. The depth to which the abutments were put down was determined by the nature of the foundation, and the probable effect of scour. The abutment sites being dry at low water, there was no necessity to use caissons, which would have been much more costly than the simple

curbs adopted. Mr. Shelford inquired what advantage was obtained by the pendulum-link suspension-bearing on the abutment, to provide for the effect of variations in temperature, instead of rollers in a frame as ordinarily adopted in England. In reply he would state that the advantage of the link-bearing was that it was not likely to get out of order. The rollers generally used were necessarily of small diameter, and in course of time wore flat and ground into the bearing-surface, becoming so choked with dirt as to prevent the free expansion and contraction of the girders. In one instance that came under his observation in India the jamming of the rollers through dirt resulted in the dislocation of the masonry of the abutment by the expansion and contraction of the girders, and in another instance the result was the crippling of the bottom chords and distortion of the top boxes of a pair of Warren girders, jeopardising the stability of the bridge. The Public Works Department had actually condemned that bridge and decided to replace it by a new one, when it happened to come under his observation. By his recommendation it was lifted off its bearings, the rollers were cleaned and adjusted, and the girders, having been replaced, resumed their true form and were as good as when first erected. The link-bearing worked freely, and could not get out of order, and was more easily accessible for cleaning and lubrication, though, with sufficient bearing-surface, lubrication was unnecessary. Instead of pendulum links as in the Jubilee Bridge, the ends of girders might be suspended to cast-iron standards by vertical flat bars or plates placed transversely to the girder, so that their elasticity allowed of the longitudinal motion of the end of the girder due to differences of temperature, and by this method there would be no working parts to get out of order. The form of structure recommended by Mr. Shelford for the cantilever was, no doubt, theoretically the more correct one; but the subject of the Paper was the erection of the bridge, not the design of the superstructure, with which he had very little to do beyond the general arrangement of a central cantilever and two main side spans. As Mr. Shelford suggested, the arched form of cantilever was adopted for the sake of symmetry, to make it uniform with the main side girders. The arched form was usually associated with strength; it took very little more strain on the diagonals and uprights to divert the strain round the arched form than if it had been designed as a polygon. The polygonal cantilever in the middle, between the two curved girders, would probably have been found fault with as contrary to good taste. At any rate, if the piers had been carried up the whole

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depth of the cantilever, with some suitable ornamentation at the top, as would have been necessary if the polygonal cantilever had been adopted, there would have been much greater obstruction to wind, and in a climate subject to cyclones of great violence that was a very serious matter. The present cantilevers opposed very little obstruction to the wind, which was a great point. In matters of taste it was not easy to give general satisfaction, but the effect of the bridge, as seen from the river, was that of lightness combined with strength. There had been several enquiries about the connection of the main girders with the cantilevers. As Mr. Wentworth-Sheilds pointed out, if the main girders had simply rested by their own weight on the end of the cantilevers, there would have been no danger of their shifting with the wind; the strongest wind would not shift them, because the friction was sufficient to hold them there. There was, however, a strong cross girder at the end of the cantilever girders, and a similar girder at the end of the main girders, and these were connected together by very strong cover-plates, so that the horizontal web of the whole bridge was perfectly continuous. That was the way they were connected, and he did not know that any better arrangement could have been adopted. Of course the superstructure might have been made into a continuous girder at that point, but in case of any little settlement of the side abutment, or anything of that kind, it would have been very difficult to say what strains might have been brought upon the bridge. It was better to let the cantilever and the main side girders all stand on their own base independently, and not to make them continuous. Another point which had been referred to was the deflection. The total depression in the centre of the main side spans, with both the spans loaded, was 3 inches. As was stated in the Paper, there was a deflection of 2 inches at the end of the cantilever. That made the deflection of the main side girders in their own length 2 inches, which was $\frac{1}{2,520}$ part of their length, nothing very extraordinary. Mr. Maynard had referred to the deflection of the iron tubes of the Britannia Bridge, which, he said, was $\frac{3}{4}$ inch only in 450 feet. The real span of the Britannia Bridge was 460 feet; but the tubes of two spans, he believed, were connected together over the centre pier, which practically made them into continuous girders, and thereby very much limited the deflection. Then, again, as Mr. am Ende observed, the deflection of a heavy iron girder could not be compared with that of a light steel girder. The Britannia Bridge tubes were very massive, and the total strain to the square foot, due to dead weight and moving load

together, was, he believed, very high; but it was probable that the strain induced by the moving load only did not contribute $1\frac{1}{2}$ ton per square inch to the total. The strain caused by the moving load on the lighter steel girders of the Jubilee Bridge was 3 tons per square inch, which accounted for their deflecting considerably more. If the 420-foot girders of the Jubilee Bridge had been of iron, they would have weighed not less than 1,700 tons, and the moving load, 840 tons, would have been 33 per cent. of the total load. As constructed of steel they weighed 1,000 tons, and the moving load was 46 per cent. of the total, so that the deflection of the steel girders was 40 per cent. greater than would have been that of iron girders of equal strength. However, even if the deflection had been considerably greater it would not have caused any inconvenience to the traffic. He thought the American practice was quite right. There could be no objection to the deflection of a bridge up to $\frac{1}{1,200}$ or $\frac{1}{1,000}$ part of its length, and it must come to that as material and modes of construction were improved, because the moving load would then bear a much greater ratio to the total weight of the bridge. The deflection of the girders was $\frac{1}{2,520}$ part of the length, but if it had been $\frac{1}{1,200}$ part it would not have affected the safety of the bridge as long as it was within the elastic limit, and there would be considerably greater deflections in long spans. Mr. Wentworth-Sheilds objected to the girders being cut through at the point of contrary flexure; but he had already stated that he did not think it would have been a good thing to have made the girders continuous from shore to shore, as there would certainly be some slight irregular settlement which would produce undue strains on the girders. In reply to Mr. Carbutt, the main girders were suspended at the shore end only for expansion, and were rigidly connected at the other end to the cantilever. The operation of floating the girders occupied only an hour and a half to two hours, whereas the time available for landing on the cantilever ends was six or seven hours, so that there was plenty of time to spare. The pontoon bridge at Calcutta, which was an ordinary road bridge, had not been superseded by the Jubilee Bridge, and for the convenience of communication between Calcutta and Howrah, the pontoon bridge must be maintained or another structure substituted. The Jubilee Bridge was about 28 miles by river above the pontoon bridge. In reply to Mr. Lewis, the cantilever was a convenient means of dealing with a width of 360 feet in mid-stream, and at the same time keeping the piers out of the deep channel; but for the shore spans, where the approach viaducts afforded a convenient platform for the erection of

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the girders, it was unnecessary to have recourse to a cantilever, which would have involved a half-cantilever span over dry ground in rear of the abutment. It would have necessitated building the girders for the intervening space between mid-channel and the abutment cantilevers at a low level, on special staging some distance above or below the bridge, floating them bodily into place, and lifting them to their permanent seat on the ends of the cantilevers, which was a much less simple operation than erecting the main girders at their permanent level, and hauling them into position on a floating stage. As pointed out by Mr. Wentworth-Sheilds, one end of the structure was stable, and the other floating and capable of better control by warps than if the bridge had been erected on a scaffolding on shore, lifted by pontoons and carried bodily into place. So far as resisting the impact of the mast of a heavily laden vessel, the junction of the cantilever and main side spans with two heavy cross girders riveted together was the strongest part of the bridge platform. As for a train at high speed getting off the line, that might or might not wreck any bridge. He did not think the multiple triangulation system afforded much better chance of safety than the single triangulation. The strength of the individual struts and ties would be less in the former than in the latter, consequently a derailed engine might destroy a sufficient number to bring down the multiple triangulation bridge. Mr. Wentworth-Sheilds would have preferred putting the two river piers 200 feet apart, dispensing with the cantilever altogether, and using girders of 500-foot span between the abutments and river piers. By this design the weight of the 500-foot spans would have been 1,400 tons, as compared with the 420-foot spans of 1,000 tons each, and so much the more difficult therefore to handle. The right-hand pier also would have fallen in deeper water, and would therefore have been more difficult to control in pitching; besides the girders of the 200-foot span would have had to be floated bodily into position. Altogether, he was of opinion that the plan suggested would have involved greater trouble, expense, and risk in erection than the plan adopted, although there would undoubtedly have been a considerable saving in material. In reply to the remarks of Sir Douglas Fox, it was quite true that, to carry the railway only, every alternate pier of the viaducts might have been omitted. The extra cost of making the viaducts strong enough for launching the girders of the side spans amounted to £2 per ton on the cost of the girders; but part of this expense was saved in cheaper labour than would have been required for cantilever work, and in greater expedition, as work could be proceeded with on the viaducts through-

out the entire length of the girders simultaneously; whereas a cantilever could only be built out one member at a time. All the difficult and dangerous work in India devolved on the engineers and foremen, and it was not easy in Bengal to procure the superior class of labour for cantilever erection; the payment to men employed on such work was at much higher rates than to ordinary labourers. In Bengal, where engineering supervision was such an expensive item in bridge construction, the element of time must also be considered, and the plan of superstructure described in the Paper was adopted because all the work could be proceeding simultaneously. Considering that the first shipment of the cantilever material was received at Calcutta on the 18th of March, 1886, and that the bridge was completed on the 22nd of December of the same year, without accident or loss of life in the erection of 3,465 tons of steel-work, although the operations had to be carried on throughout the hot and rainy season and while the river was in full flood, it would perhaps be admitted that the plan adopted was well suited to the conditions under which the work had to be done. In reply to Mr. M. am Ende, he would observe that, in sinking cylinders and caissons, it frequently happened that the earth was wholly removed from beneath them, and a cavity formed extending beyond their lower edge, under which conditions they were sustained entirely by side friction. From observations made in such cases, he had found that, at depths of 40 feet and upwards, it required weight of 10 or 12 cwt. to the square foot of skin surface to overcome such friction, and, as the friction of repose tended to increase with time, he thought it justifiable to take credit for at least 5 cwt. to the square foot as the sustaining resistance derived from side friction. Mr. M. am Ende thought it might have been better to put the girders together with one end overhanging in the first instance, to save the trouble of protruding them 75 feet on the small rollers. This operation gave very little trouble, while to have built the girders with one end overhanging would, to a considerable extent, have sacrificed the facility of erection on the viaduct. Mr. Baker had drawn attention to some points of great practical importance. It was interesting to know that the slinging of the girders of a bridge at Hull on a pendulum link to allow for expansion had worked well for forty years. He first adopted it fourteen years ago for the adjusting girders (160 feet span) of the floating bridge over the Hooghly at Calcutta. In that case the arrangement not only provided for the expansion and construction of the longitudinal girders of the bridge 1,530 feet long over all, but formed the horizontal hinge on which the ends of the adjusting girders worked,

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as the bridge rose and fell with the tide twice in twenty-four hours. This mode of suspending the girders had given great satisfaction. With the load on the bottom chord the ties of the girders of the Jubilee Bridge sustained a considerably greater strain than the struts, and therefore were heavier in section than the struts, so that the appearance of the bridge in this particular conveyed a correct impression of its actual condition. He, however, fully concurred with Mr. Baker as to the suitability of the tubular form for the compression members of large structures, in which a given amount of metal was undoubtedly disposed to the best advantage to sustain a compressive-strain. The value of the cylindrical form for struts, as adopted at the Forth Bridge, was recognized by Brunel early in the days of iron bridge construction, and introduced by him, among other examples, for the top booms of the Chepstow Bridge trusses nearly forty years ago. Mr. Baker had correctly remarked that the general design of the bridge hinged almost wholly on the piers, and that it was the necessity for employing pontoons for pitching and sinking the caissons which suggested their use for the erection of the bridge. In reference to the Poughkeepsie Bridge, it must be remembered that the gentle stream of the Hudson River was very different from the surging current of the floods and bores in the Hooghly, where the mooring and controlling of the caissons previous to pitching was one of the chief difficulties to be contended with. It was impossible to adjust and hold the floating caissons accurately in position, without the heavy moorings and tackles by which they were secured at the bottom with the aid of the pontoons for working the ground tackle, and steadying the topside of the caissons, and preventing them from swaying about with the stream. Moreover, it took five Bengalees to do the work of one European, and therefore a platform of ample area, such as that afforded by the pontoons, was required for native labour; and it might here be stated that in the numberless instances in bridge erection, where the combined concentrated physical force and intelligence so readily available in Europe and America was required, such work was carried on at great disadvantage in Bengal where the physical power of individuals was so feeble. This was illustrated by the fact referred to by Mr. Baker that, in the Poughkeepsie Bridge, it cost no more to erect a cantilever span by overhang than an independent span on staging. It might also be noted that the pontoons were built on the lines of the vessels used for the inland river service, and as such were readily saleable in Bengal; though at present they were being utilized by the Railway Company as landing stages at the Howrah terminus. Practically, he did not believe that the river piers of the bridge

could have been pitched and sunk without the pontoons; and, with the pontoons available, no more economical or expeditious means of placing the main side spans in position than that adopted could have been devised. The American and Canadian practice of erecting the superstructure of bridges by building out in panels, or by overhang without scaffolding or staging, had been referred to in a general way. This, as described in the Paper, was the plan adopted in the erection of the projecting ends of the cantilevers of the Jubilee Bridge; but in the as yet unfinished Poughkeepsie Bridge, it appeared that recourse had been had to staging for the erection of spans of 525 feet, at a height of 212 feet above the water; this, on the score of expense, was certainly a case in which it would have been desirable, if possible, to dispense with the use of staging. The fact was no general rule could be laid down. On Indian railways the engineers, who had to carry out the erection of bridges, were not entrusted with the designing of girder work that had to be sent out from England; and in erecting them they had to consider the means at their disposal, and that plan was the best in which due regard was paid to economy and expedition. No doubt it was the case that the momentum of a train, suddenly arrested on the Hooghly Bridge, must take effect on the top of the river piers; but, as Mr. Baker had noticed, the point was not very important in the case of this bridge, of which the river piers were the strongest part. The steel standards were firmly bolted to the masonry, the dead weight in their base was 3,000 tons, and though their breadth was 14 feet, their actual base was 20 feet wide, so that they were well able to sustain a horizontal thrust at the top of 200 tons, or even three or four times that amount, quite independently of the holding-down bolts, which contributed another 1,500 tons to their stability. The connection of the main girders with the cantilevers had been taken exception to as an apparently weak point; and, if the main girders had been connected with the cantilever by an expansion joint, instead of being solidly riveted together as described elsewhere, he feared the criticisms might have been still more severe. The point raised by Mr. Baker was of great practical importance, and showed the necessity of making the piers and abutments, of bridges and viaducts, sufficiently massive to withstand the horizontal thrust resulting from the sudden application of train brakes. In girder bridges of moderate span, wherever it was practicable, he adopted the plan of designing them to carry a layer of 18 inches of ballast, and laying over them the ordinary permanent way, quite independent of, and unconnected with, the bridge platform. By carrying the flooring plates on the bottom flanges of the cross girders this did

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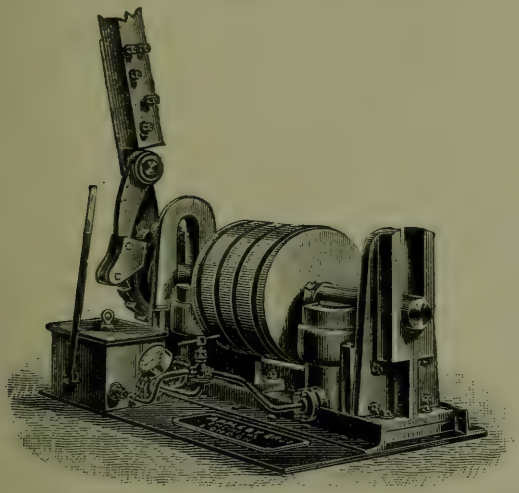
not increase the thickness of the platform, and was preferable to the usual plan of fastening the permanent way to the platform or roadway girders, which, of course, must transmit any end thrust caused by the application of train brakes direct to the superstructure of the bridge. The reasons for the adoption of the cantilever mode of construction, as to which Mr. Wolfe Barry had enquired, were because the deep channel 500 feet wide had to be bridged in one span, and when the arched structure originally proposed by him was not approved, he had recourse to the central cantilever as the most convenient method of limiting the span of the girders for crossing the deep channel. The range of tide on the dates of launching the girders was 4 feet 6 inches; it required about 2 feet 6 inches to float the girders, and the tide continued rising during the time, one and a half hour in the one case and two hours in the other, that the girders were being floated across, and for some time after the girders had completed their journey; consequently, when the girders arrived at the cantilever, their ends were a considerable height above their permanent seat on the cantilever, and as it took several hours of ebb-tide before the water fell to the level at which the girders landed on the cantilevers, there was plenty of time to spare. The particular part of the river bank at the site of the right abutment was not subject to alteration. As stated in the Paper, the right abutment as well as the river piers were founded in a bed of hard yellow clay. This bed of clay was of great thickness, was impermeable to water, and in sustaining power and in resisting the action of running water was but little if at all inferior to solid rock. For buildings, factories, chimneys, &c., with comparatively shallow foundations, it was usual to limit the weight to about 1 ton to the square foot, but it was more important to secure uniform pressure on the foundations, as any considerable difference of pressure resulted in unequal settlement, causing cracks in the walls and arches of buildings. He entirely endorsed Mr. Barry's observation that in these structures of magnitude, engineers should look to what was cheapest, and what would do the work in the best way, and that it was a mistake to sacrifice a large sum of money for any fancied improvement of an unessential nature. In reply to Mr. Waring's enquiry, the tensile- and compressive-stresses under a distributed load of 2 tons to the lineal foot nowhere exceeded $6\frac{1}{2}$ tons to the square inch, while provision was made in the platform and bracing of the main girders for the maximum panel load due to the heaviest type of locomotives.

Correspondence.

Mr. C. J. Appleby observed, with reference to the launching arrangements, that he should have expected the small rollers to give some trouble, notwithstanding the number used; but the whole of the work, which had been so lucidly described, had evidently been carefully considered in every detail, and his only object in referring to this part of it was to mention some successful Mr. Appleby.

Fig. 1.



appliances which had been adopted for launching a bridge over the Rio Jacuhy, in Brazil. In this case, as in many others, it was much more convenient and economical to deliver the materials, and rivet up the bridge complete on one side of the river, than to carry on the work on both sides. Staging, or floating lifting arrangements, were alike impracticable, and as the front end of the bridge might "sag" a little, it was desirable that the appliances should be readily adjustable. They consisted of ten twin hydraulic jacks, of the construction indicated in Fig. 1. Each pair was mounted on a strong wrought-iron bed-plate, with shackles for lifting, and bolts for securing, the bed-plates to the staging, abutments, or piers. Each pair of jacks was provided with differential pumps, and the necessary pipes and valves between the pumps and the cylinders. The pump of larger diameter was,

Mr. Appleby. of course, used for running up quickly, or for light loads, and the smaller one for the maximum duty, but both could be worked by one man. The object in having one pump to each pair of cylinders was to ensure both rams being maintained at the same height. The heads of the rams were used as bearings for a steel shaft carrying a roller about 2 feet in diameter, which was grooved to take the heads of the rivets, and thus give the bottom flange of the girder a fair bearing and good rolling-surface; the end standards were merely intended to keep the shaft in its proper position. As there might possibly be a load of 120 tons on the roller, each jack was tested to 100 tons, or 200 tons for the pair. The main girders having been built on packings high enough to allow the jacks to be passed under them at certain places, and a few cross-girders put in to act as stays, the jacks were set to work, and lifted the portion which had been completed high enough to allow the packings to be removed and used on another section. The pawl, working into a ratchet-wheel on one end of the roller-shaft, was provided with a long pole worked by two men, and in this manner the men at each pair of jacks, working by signal, propelled the bridge forward until it had been completely launched. If the front end was too low to ride over the rollers which had been fixed on the pier or abutment, a few strokes of the pumps on the jacks, carrying the back end of the bridge, quickly raised it to the proper level. He had been unable to ascertain what had been the cost of launching the bridge by these appliances, or the time occupied; but he had learned that both the time and the cost were very much less than had been estimated by either the engineers or the contractor. The bridge was constructed for the Porto Alegre and Uruguyana Railway; the length was 525 feet, in three spans, and the total weight was about 340 tons. These appliances had been designed under instruction from Mr. F. C. Miers, M. Inst. C.E.

Mr. Cunningham. Mr. J. H. CUNNINGHAM remarked that the work executed in erecting the Hooghly cantilever was in some respects similar to that done in putting up the cantilevers of the Niagara bridge. In both cases part of the material was erected on staging, and part was built out panel by panel. But there was a great difference in the speeds at which these operations were carried out. At Hooghly 1,465 tons were erected in seven months, being about 210 tons per month, whereas at Niagara[1] 1,565 tons were erected in two months, being at the rate of 780 tons per month. It might be fair to take

[1] Transactions of the American Society of Civil Engineers, 1885, vol. xiv. pp. 516 and 519.

into consideration the fact that at Niagara there were two cantilevers which were erected simultaneously; but, even if a comparison was made between the rates of working on each of them, and the rate on the Hooghly, it would be found that the American bridge progressed about twice as fast as the Indian one. For one of the American cantilevers was put up in two months, or at the rate of 390 tons per month, and the other was finished in one month and a half, being at the rate of 520 tons per month. The more rapid working at Niagara might have been caused, to some extent, by railroad competition, which made it important for the company to have the new bridge opened for traffic at the earliest possible moment, as well as by employing more skilled labour than could be obtained at Hooghly. But making full allowance for these circumstances, might not the comparatively slow progress of the erection at Hooghly have been partly caused by the use of rivets in the main joints, instead of pins, as adopted at Niagara? American engineers adhered to the pin-joint as firmly as English engineers did to the riveted-joint, and it might be well to consider whether (1) riveted work could be erected as quickly as pin-connected work, and if not, whether (2) a riveted bridge possessed any advantages which compensated for the longer time which must be spent in putting it together. Mr. Cunningham.

Mr. R. E. JOHNSTON considered the Hooghly Bridge an admirable example of the best means of effecting the crossing of a river, the bed of which was soft alluvium, liable to have its volume and velocity greatly increased in the rainy season, which was a distinguishing characteristic of many of the rivers of India. In the earlier Indian bridges the error was made of adopting short spans involving numerous piers, which impeded the flow of water and induced serious scour, which led to their being undermined and the ultimate destruction of the bridge. This experience pointed to the desirability and economy of adopting large spans, with piers founded at a much greater depth than was the practice with the earlier bridges, where the river-bed yielded readily to the effect of scour. The design of the superstructure was similar in principle to that employed by the late Mr. C. Shaler Smith for bridging the Kentucky River.[1] In that case three spans of equal width were adopted; but in the bridge under consideration, owing to the nature of the cross section and the traffic on the river, the central span was about one-fourth of the two side openings. In both examples, however, cantilevers resting on piers Mr. Johnston.

[1] Minutes of Proceedings Inst. C.E. vol. liv. p. 182.

Mr. Johnston. carried one end of the girder that bridged the openings between their outer ends and the abutments. From the illustrations it would appear that the cantilever-girders were bolted down with steel standards, on which they rested for their entire width, the result being that when the cantilever deflected the weight was carried on the outer edge of the standards, and so caused the centre of pressure at the base of the pier to deviate from the centre of their width, which resulted in an increase in the average intensity of stress per square foot on the foundation. This would appear to point to the desirability of reducing to the least possible extent the bearing on the standards, or the adoption of knuckle-bearings, so as to ensure the centre of pressure under all possible conditions of loading coinciding with the centre of the piers, as was done in the case of the Kentucky Bridge. Credit had been taken for side friction in the piers at 5 cwt. per square foot. This was an uncertain quantity and difficult to estimate, as it was impossible to decide upon the weight supported directly on the foundations and that carried by side friction. Perhaps the Author would state the data on which this estimate was based.

Mr. Mansergh. Mr. JAMES MANSERGH stated that twenty-four years ago, when acting as contractor's agent on a line of railway in South Wales, he had a very instructive experience in connection with cylinder sinking. He was building a bridge of 168 feet span over a river, and each of the main girders rested at each end upon a 6-foot cast-iron cylinder. All four had been got down through the valley gravel, which was full of water, by means of divers, and had been sunk through some 20 feet of dry and very strong underlying clay. During the sinking about 25 tons of rails had been resting on the top of each cylinder, and the company's engineer gave instructions to stop sinking after he had satisfied himself that the foundation was sufficient. The cylinders, which were standing a foot or two above the top of timber guide-frames resting on the ground, were then filled with concrete; and he had taken all dimensions and got out the lengths of making-up pieces required to bring the cylinders up to bed-plate level, when a flood in the river submerged the whole work to the depth of 10 or 12 feet deep for about a week. When the water had subsided he was puzzled and alarmed to find that one of the cylinders had gone down 2 or 3 inches. On thinking the matter over, he concluded that the water had got down the outside of the cylinders (which were clean smooth castings), and had diminished the friction by lubrication, and that this, aided by the hydrostatic pressure, had caused the settlement. He

immediately put three lengths on each of the four cylinders, which brought them up to about formation level and filled them with concrete. He then stacked, first on one pair and then on the other, permanent metals, cross girders, &c., weighing together 286 tons 12 cwt., with the result that on the east side of the river the cylinders went down about 1 foot and on the west side nearly 2 feet, and afterwards remained stationary. The load on the bottom was then about 7 tons per square foot less the friction on the sides. It would be instructive to know from what experience the Author arrived at the figure of 5 cwt. per square foot, as the value of the frictional support of the river-bed on the surface of the caissons. With reference to riveting or bolting up permanent way without provision for expansion and contraction, an incident occurred when he was on the Dom Pedro II Railway in Rio de Janeiro, about 1858, to which he might refer. It had been necessary to lay several miles of permanent way on a clay bank across a swamp without any ballast. The rails were Barlow's patent, 90 lbs. per yard and about 11 inches broad at the bottom, and they were connected rigidly together by means of a fishing-saddle under the joint riveted to each metal. The two rails were held together to gauge by angle-iron ties, and, to allow of the rails bearing fairly on the formation, grooves had been cut in the hard-baked clay for these ties. There being no ballast to box up with, the rails were exposed to the full blaze of the sun over their whole surface, and so got extremely hot. Riding down the line about Christmas, one afternoon, he found in one place eight lengths of metals (192 feet), and close to it six lengths (144 feet) up in the air, the maximum rise or versed sine in the first case being 2 feet 9 inches and in the second 2 feet 3 inches. These rails might have been riveted together some morning early after having been exposed to a night temperature below 60° Fahrenheit, and the heat in the sun might have exceeded 160°. The line was straight for about 1 mile, so that there was no chance of their expanding except by "hog-backing" each rail, or by their getting up in groups in the way described. He had never heard of a similar experience, and it might be interesting to put it on record. Mr. Mansergh.

Mr. T. Seyrig remarked that the difficulties which had to be overcome in the erection of the Hooghly Bridge were not very likely to present themselves often. The way they had been solved was interesting and instructive. Success had been complete, although on many points it might perhaps have been desirable to provide for greater security. The habitual state of the river and tides must give rise to many apprehensions. The floating out of Mr. Seyrig.

Mr. Seyrig. the main spans took one hour and a half in the first instance, and two hours in the second. The space of time occupied by both operations was certainly very short, and it proved how complete and excellent were the preliminary arrangements. Nevertheless, an enormous risk would have been run if the slightest hitch had taken place, or if the tide had been irregular from some unforeseen cause. Had the rolling out been delayed in any way high water would have been lost, and the forward end of the girder resting on the pontoon could not have been lodged on the cantilever. Nothing had been said as to the possible consequences of such a mishap, but a complete withdrawal would probably have been necessary, and even this might have been attended with considerable risk. From the point of view of economy, it might be doubted whether the design adopted was the more satisfactory one. The total weight of superstructure, given at 3,465 tons of steel, made it one of the heaviest modern bridges. It did not appear that the clear span of 540 feet on either side justified such a large expenditure of material. The real girder-span was 420 feet, and the adoption of the cantilever must be justified by giving it no more weight than the principal span. It was, in fact, much heavier. This might be due to the unfavourable proportions given to the cantilever. A gain would certainly have resulted from the enlarging of the central span from 120 feet to 180 feet. Greater stability would have been ensured thereby, while it was doubtful whether any special difficulty would have been met in the foundations by displacing each pier 30 feet. Such at least seemed to be the indication furnished by the sections of the river. No calculation was given of the strains in the several parts of the bridge, and it would be of interest to know how they were met. The sharply curved ends of each girder, more especially, appeared open to criticism, for in these spots very heavy bending-strains might be found to be supplementary to the axial strains which alone ought to exist in trussed structures. The mode of distribution of the elements composing the girders seemed barely justified from a theoretical point of view, especially in the cantilever. It must always be regretted when, in an important work, the desire to satisfy the eye by fitting or graceful lines had been overlooked. It was a matter of judgment how much importance could be attributed to this desire; but if both the economical question and that of stability were well solved, the artistic feeling might also claim satisfaction. In many of the modern systems of bridges this point had been neglected in a most unsatisfactory way, and American engineers had rendered the development of

artistic feeling a bad service through the invention, or rather extension, of the cantilever system. It was to be hoped that, should it continue to be extensively used, some form of girder more agreeable to the eye might be found than either those built in the United States, or those now building or built in India, of which the Hooghly "Jubilee" Bridge was a prominent example. Mr. Seyrig.

Mr. Bindon B. Stoney observed that in the United States it was usual to provide for a range of temperature to the extent of 150° Fahrenheit. The Author had adopted 100° Fahrenheit (55°·5 Centigrade) as the possible range of temperature at the Hooghly, and as the coefficient of linear expansion for steel for 1° Centigrade was 0·00001145, the alteration of length of the superstructure of the bridge, 1,200½ feet long, for a range of 100° Fahrenheit, would appear to be Mr. Stoney.

$$55{\cdot}5 \times 0{\cdot}00001145 \times 1{,}200{\cdot}5 \times 12 = 9 \text{ inches},$$

in place of 6 inches, which was given in the Paper; and the alteration of length of the central girder in the span of 120 feet 6 inches between the river-piers would amount to

$$55{\cdot}5 \times 0{\cdot}00001145 \times 120{\cdot}5 \times 12 = 0{\cdot}92 \text{ inch}.$$

As in this length of the central girders the expansion and contraction were taken up by the elastic bending of the steel standards which supported them, each of the latter should be capable of rocking back and forwards to the extent of 0·46 inch, or 0·23 inch on each side of its neutral position, supposing that the connection was made at the mean temperature of 90° Fahrenheit. The standards were vertical cellular structures, weighing 205 tons each, 30 feet high, and (by scale) 14 feet thick, formed of plates and angle-bars, riveted together and secured to the brickwork of the piers by holding-down bolts and anchor castings. The stiffness of such massive standards must be very great, and it would be interesting to know if observations had been taken of their actual range of motion. Moreover, they would themselves be liable to bending under the influence of temperature. As steel altered 0·000076 of its length for 1 ton stress per square inch, a change of temperature of 6°·6 Centigrade was capable of developing a stress of 1 ton per square inch, and a range of 55°·5 Centigrade might therefore develop a stress of over 8 tons per square inch. Supposing that the standards did not rock appreciably, and that the girders were connected to them at the mean temperature, then the lower flanges of the central girder over the span of 120 feet 6 inches might theoretically be subjected to 4 tons stress per square

Mr. Stoney. inch, plus or minus their normal inch stresses. Mr. James Barton made an experiment in 1854 at the Boyne Viaduct with a large screw to find what pressure was required to rock one of the river piers. The pier was masonry, 85 feet 3 inches high from the bottom of the plinth to the top of the pier; its horizontal section at the top was 34 feet 6 inches by 11 feet 6 inches, and at the bottom of the plinth 41 feet by 17 feet. Using 0·1 as the coefficient of friction for the screw, a calculated pressure of 140 tons against the top of the pier pushed it over $\frac{3}{16}$ inch, and a pressure of 197 tons dislocated some of the masonry. These matters were of some interest in connection with the effect of temperature on the Forth Bridge and its bed-plates. It would add to the value of the Paper if the Author would give fuller details of the dimensions and bearing surface of the pendulum links and steel pins, and the pressure of the insistent weight per square inch of their bearing area, and would also state whether they required lubrication.

Mr. Wilson. Mr. J. M. Wilson, President of the Franklin Institute, thought the work could hardly have been done better. He considered the feature of the central double cantilever a particularly attractive one, exactly suited to the requirements of the case, and that it contained in itself a valuable example as a precedent for future occasions. Probably the best previous instance of this principle of construction was the bridge over the Kentucky River, U.S., on the line of the Cincinnati Southern Railway, erected in 1876–77. In this bridge, which was 1,138 feet long, and 275·5 feet above low-water, the centre span was continuous, the ends projecting over the piers as cantilevers, and the two side spans resting on them. The method of erection was necessarily different from that adopted in the present case. The iron pontoons appeared to have been well designed for their purpose, and gave great facilities for sinking the caissons, at the same time coming into effective use for the moving into place of the shore spans in a novel and expeditious manner. Mr. Wilson was not aware of the relative cost of brickwork as compared with ironwork at Hooghly, but other things being equal, his preference would have been for plate-girder connections on the approaches, on brick or iron piers, in spans of, say, about 50 feet. Any extra strength required in the approaches next to river, during the erection and movement of the shore spans, could have been easily provided for by temporary timber supports and bracing. It might be that the question of continuous foundations, and the appropriation of all the bearing possible for these foundations, had influenced the type of ap-

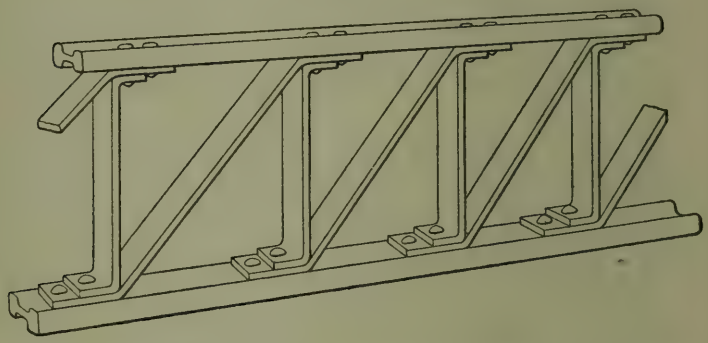
proaches adopted; but he thought this could have been arranged, and that the dead load might have been considerably lessened. There appeared to have been nothing peculiar in the erection of the cantilever span; but the method of erecting the shore spans and of moving them to place by the pontoons was exceedingly interesting, and the work seemed to have been done with remarkable rapidity and success. It would be difficult to compare this work with American practice, the conditions were so different from the usual examples in the United States. In fact, with large structures of this kind, each case had its own peculiar conditions, requiring its own special treatment. No details of the superstructure had been given, and it would hardly be possible or fair, without more information, to compare it with American practice; but in American hands the form of truss and details of construction would probably have been different. The train-loads for testing seemed light as compared with American practice, although the locomotive service was heavy. In the United States train-loads in actual practice sometimes reached 3,000 lbs. per lineal foot of track, and at least one prominent road had adopted a standard of 4,000 lbs. per lineal foot for train service, with two locomotives in addition. Mr. Wilson.

Sir Bradford Leslie, in reply to the correspondence, remarked that besides the disadvantage of inferior native labour, the Hooghly Bridge cantilever was erected in the most trying season of the year, when the iron was often too hot for handling, and when much time was lost in consequence of the impossibility of working in the downpour of the tropical rains; at other times the work was delayed by the floods making it difficult to navigate the lighters with material. In this it was necessary to be very careful, as the loss of a single member would have delayed the work six months, while it was replaced from England. Added to all these sources of delay, the work was often stopped while the foremen were *hors de combat* from sunstroke, fever, and dysentery, brought on by exposure at a season of the year when outdoor work was usually suspended. In the English climate the work might have been done in half the time, which would have been at about the same rate as the work at Niagara. The advantage of riveted work over pin-connected work was its superior stiffness. In a riveted bridge the struts were all columns fixed at both ends; whereas a pinned strut depended entirely on its own stiffness to resist buckling. To secure, in a pin-connected girder, equal stiffness with a riveted girder, a greater weight of material was necessary for special stiffening and bracing of the compression members, and if this Sir Bradford Leslie.

Sir Bradford Leslie.

extra material was omitted, the strength of the pin-connected girders must be inferior to the riveted girder. In adopting links and pins for trussing a solid riveted frame, as at Chepstow and Saltash, it appeared to him that Brunel had solved the true application of link and pin construction for taking up the tensile-strains of large girders. In these bridges all the struts were fixed at both ends, and the weight was transmitted to the tensile chains by adjusting wedges or screws. Although he was an advocate for the use of riveted girders, on account of their superior stiffness, he could not say that he approved of the type of construction ordinarily adopted in riveted girders of large span, which had the defects pointed out by Mr. Max am Ende, in that the material could not always be disposed so that the neutral fibre of the section coincided with the line of strain. The large gussets no doubt added greatly to the stiffness of the structure, but involved an

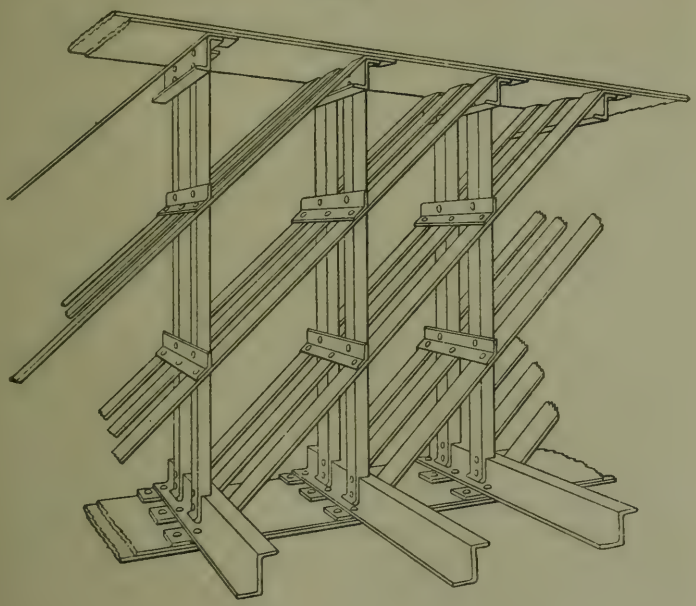
FIG. 2.



immense number of rivets, many of them difficult of access, to take up the strains; besides, the top and bottom boxes especially were difficult to paint, and got choked with dirt, which retained moisture and induced corrosion. For utilizing old double-headed rails for constructive purposes, he had invented a simple type of N girder, in which the vertical stresses were transmitted direct between the oblique ties and the upright struts by a bent knuckle (Fig. 2), so that the rivets through the top and bottom chords were required to transmit the horizontal stress only. He had tested these girders, and had used them for railway bridges up to 36 feet span, and for flat roofs and floors of much larger span, and had found them quite as stiff and elastic as plate-girders, and much less expensive. The smithing of steel bars by hydraulic pressure was now so cheap and rapid an operation, that a

slight modification of this system of construction would, he believed, be very superior to the ordinary style of girder with the box section of top and bottom chords, even for large spans. It would be seen that in a multiple triangle girder of the proposed type (Fig. 3), the top and bottom booms consisted simply of flat plates. The floor-beams rested, as they should, direct on the tension-bars, and transmitted the vertical strains they received from the struts direct to them; the only rivets through the tension-bars were those required to transmit the horizontal stresses to the top and bottom chords, therefore these bars could be made as Sir Bradford Leslie.

FIG. 3.



nearly as possible of the net section required. The edges only of the plates and bars were seen in side elevation, so that the material was disposed almost exactly in the theoretical lines of strain, and none of the material was subjected to bending-stresses, while the minimum area was exposed to the wind. The riveting also was reduced to the minimum, and was conveniently accessible for machine riveting. The extreme lightness of girders of this type would greatly facilitate erection without staging. It was only necessary to take care that, in forging, the metal was upset, so that the bars should carry their full section at the elbow; by the

Sir Bradford Leslie.

use of proper cast-iron moulds this was easily secured. In reference to Mr. Johnston's remark, the base of the standard was 20 feet wide, while the standards themselves were only 14 feet wide. As designed, the weight of the cantilevers and load thereon (excepting a length of 30 feet of the bottom box, roadway platform, and moving load) was transmitted through the upright strut over the centre of the standard, and through the inclined strut of the adjoining inside panel to the centre of the large gusset over the standard. These struts were very stiff, and it was impossible to tilt the gusset so as to bring the weight on the outer edge of the standard, as supposed by Mr. Johnston, without bending them. Owing to the curved form of the top boom between the piers, any deflection of the cantilever tended to depress the bottom box of the inside as well as of the outside panel adjoining the standard, so that there was no tendency to tilt the large gussets in either direction. Mr. Mansergh's observations, on the effect of a flood in lubricating the surface of cylinders resulting in settlement, were not applicable to the caissons of the Jubilee Bridge, which were never dry from the date they were pitched. The hog-backing of the Barlow rails was a well-known defect of that section of rail. He remembered a similar case, which occurred in 1852 or 1853, in a cutting on the South Wales Railway, when first these rails were used. The expansion of the Jubilee Bridge girders was provided for, as explained in the Paper, by allowing a play of $\frac{1}{2}$ inch in about a dozen rail-joints; the holes in the fish-plates being made oval, and the nuts of the fish-bolts not being over tightened, the rails slid freely at the joints, and the line, being well ballasted with stone, there was no danger of buckling. With reference to Mr. Stoney's remarks, the extreme range of temperature, of 100° Fahrenheit, was between a minimum of 40° and a maximum temperature of 140° in the sun. It was the expansion of the bottom chords only that affected the length of the bridge; any excess expansion of the top chords, which were chiefly exposed to the sun's rays, only increased the camber of the girders. The sun's rays could not by any possibility take effect on more than one-sixth part of the surface of the bottom chords exposed to the air, the maximum temperature of which, in Lower Bengal, was about 106°; thus the greatest difference in the average temperature of the steel was probably not more than 70° Fahrenheit. This would give a possible difference of 6·66 inches in the total length of the bridge, and of $\frac{5}{8}$ inch in the length between the centres of the river piers. No such difference as this had, however, as yet been observed in the total length of the bridge, and it was

probable, therefore, that the steel standards, 30 feet high, did not oppose any considerable resistance to the small amount of expansion, about $\frac{1}{6}$ inch in either direction; this was the maximum that could take place in the bottom booms of the cantilever. The dead weight at each end of the girders of the side spans was 250 tons, which might be increased by the live load to 460 tons, and this was carried on a steel pin 15 inches in diameter, bearing in two pendulum links each 4 inches thick; the pins were kept clean and lubricated, as it gave the watchmen something to do; but he believed the bearing might be left unlubricated with perfect safety. Mr. Seyrig had remarked that an enormous risk would have been run if the slightest hitch had occurred in floating out the main spans, or if the tide had failed from any unforeseen cause. The plan adopted for placing the main girders in position was not free from risk, and in bridges of magnitude, over rapid rivers, some risk was unavoidable, whatever plan might be devised. A staging, such as that used at the Poughkeepsie Bridge, might be burnt, or carried away by floods, while the girders were in course of erection. It was for the engineer to decide how far the saving of expense justified the adoption of any particular plan for erecting the superstructure. From his own experience he had found that when the engineer could give his personal attention to every detail, the element of risk was practically eliminated. The erection of girders of 500 feet span, or more, would have been a much greater undertaking than the erection of the superstructure as designed, and the element of risk, to which Mr. Seyrig objected, would have been greatly increased. In reply to Mr. J. M. Wilson, he would observe that, no doubt, other things being equal, with plate-girder connections for the approaches on brick or iron piers, the dead weight on the foundations would have been considerably reduced. But with this type of structure the moving load of 500 tons would have borne such a much higher ratio to the total load on the foundations, that the soft alluvial earth might have been compressed, and have yielded during the rolling out of the girders. Brickwork was cheap in India, and by making the approach viaducts very massive, the foundation was thoroughly consolidated; and as the moving load was a comparatively small portion of the total load on the foundation, the danger of any settlement during the launching of the girders was minimized.

Sir Bradford Leslie.

31 January, 1888.

GEORGE BARCLAY BRUCE, President,
in the Chair.

The discussion on the Paper by Sir Bradford Leslie, on the Hooghly Jubilee Bridge, occupied the whole evening.

7 February, 1888.

GEORGE BARCLAY BRUCE, President,
in the Chair.

The following Associate Members have been transferred to the class of

Members.

THOMAS ANDREWS, F.R.S.E.
CHARLES HOPKINSON, B.Sc.
FRANK HUDSON.
CHARLES ALGERNON MOREING.
BENJAMIN CRISPIN SIMPSON.
HORACE WILMER.

The following Candidates have been admitted as

Students.

JOHN HENRY ASHWORTH.
BENTLEY ASQUITH.
CHARLES DAVIDSON BARKER.
ARTHUR WILLIAM BISHOP.
MONTAGUE THOMAS NELMES BLUCK.
JAMES ASHTON BOWKER.
JOHN BOWMAN.
GEORGE FRANK BURN.
WALTER CLEMENCE.
ALFRED ERNEST COCHEME.
ERNEST ALFRED CUMMING.
HERBERT BOULTON DENHAM.
JAMES GOODMAN.
EDWIN WALTER GREENWELL.
JOHN MARCHMONT GREGORY.
RICHARD GUEST.
ROBERT GUSTAVUS HARDING.
FRANK HOVIL.
WILLIAM HENRY KER HOWARD.
ALBERT WILLIAM LAWSON.
ARTHUR LAZENBY.
FRANK THEODORE MARSHALL.
PHILIP FRANCIS MORTON, B.Sc.
WILLIAM POOLE.
GEORGE WILLIAM MIDDLETON PUMFRETT.
ERNEST WILLIAM PUTMAN.
EDMUND DUNLOP PUZEY, B.E.
WILLIAM JAMES QUODLING.
JOHN BERTRAM MAIS RIDOUT.
THOMAS ROOKE.
PREO NATH SEN.
CHARLES FREDERICK SMITH.
JAMES NOËL SPARKS.
HUGH OWEN TAYLOR GREEN STEPHENS.
CHARLES LÉOPÔL STRAPP.
HERBERT WALTER STRIDE.
FREDERICK WILLIAM SUTCLIFFE.
JAMES SUTHERLAND.
JAMES THORNTON.
WILLIAM STEPHEN WATSON.
HENRY LAWRENCE WHEATLEY.
BENJAMIN JAMES WOLFENDEN.

The following Candidates were balloted for and duly elected as

Members.

JONATHAN ROBERT BAILLIE.
THOMAS GRAY.
CHARLES SCOTT MEIK.
CHRISTOPHER JOHN MULVANY, M.A., B.E.
HENRY NORLANDE RUTTAN.
JOHN MOORE SMAIL.
HAMILTON SMITH, Jun.
JOHN DEANE TILNEY.

Associate Members.

Frederick Dixon Clark.
Francis Edward Cockshott.
Charles Spencer Eaton Crakanthorp.
Ponsonby Moore Crosthwaite, B.A., B.E.
William Macdonnell Mitchell Dowdall.
Edward Frobisher, Stud. Inst. C.E.
Thomas Griffiths.
Hartley Grunwell.
Charles Edward Hannaford, Stud. Inst. C.E.
Edmund Lyons Wellesley Haskett-Smith, Stud. Inst. C.E.
Gilbert Macintyre Hunter, Stud. Inst. C.E.
Sydney Hutton Cooper Hutchinson.
John Broadhurst Kent.
John Kirkaldy.
Robert Knowles.
Philip Vincent Lander, Stud. Inst. C.E.
George Morgan Lane.
Arthur Edwin Trevillion Lees, Stud. Inst. C.E.
Frederick James Leigh.
Johan Rudolf Lilljegvist.
Percy Archibald Low, Stud. Inst. C.E.
Samuel William Ludbrook.
George William Lund.
Thomas Walter Warren Melhuish.
Robert Jarratt Money, Stud. Inst. C.E.
Arthur Edward Nicholl, Stud. Inst. C.E.
Alfred William Long Parkhouse, Stud. Inst. C.E.
Arthur Gaved Phillips.
Alexander Brown Portus.
Edward Sandeman, Stud. Inst. C.E.
George Samuel Searight, B.A., B.E.
Frank Sheldon.
Henry Alexander George Sherlock.
Charles Liddell Simpson, Stud. Inst. C.E.
Basil Eustace Smith.
Thomas Reader Smith.
Edward Stallibrass, Stud. Inst. C.E.
George Frederick Thompson.
Louis Edward Tylor.
George Waddell, Stud. Inst. C.E.
Samuel Sugden Waddington, Stud. Inst. C.E.
Reginald Henry William Warneford.
Edward Wilkinson.
John James Wright.
Hugh Copner Wynne-Edwards, Stud. Inst. C.E.

Associates.

John Alexander Radcliffe.
Alexander de Courcy Scott, *Major-Gen.* late R.E.

(*Paper No. 2208.*)

"The Alexandra Dock, Hull."

By Arthur Cameron Hurtzig, M. Inst. C.E.

The mercantile community of Hull, after several attempts to free themselves from the monopoly enjoyed by the Hull Dock Company and the North-Eastern Railway Company, obtained an Act in 1880 for the construction of the Alexandra Dock on the foreshore of the Humber at Hull, in conjunction with the Hull and Barnsley Railway.

As 152 acres of the site of the works, out of a total of 192 acres, were below high-water mark, and extended considerably below low-water mark, the range at spring-tides being 22½ feet, an embankment, about 40 feet high and 6,000 feet long, had to be constructed to reclaim the required foreshore (Plate 2, Figs. 1 and 4). The actual works comprised a dock of 46½ acres, with 2 miles of dock walls from 52 to 62 feet in height (Plate 2, Fig. 2), two large graving-docks, a lock 550 feet long and 85 feet wide, dredging an entrance channel through the Hebbles shoal, erecting pumping-machinery, laying 12 miles of lines of way, the construction of sheds, and various minor works. The works were commenced in January, 1881, during a very hard frost, and the dock was opened for traffic in July, 1885; and as the works were stopped, for financial reasons, for nearly five months in the latter half of 1884, their construction occupied only six weeks more than the originally stated time of four years, notwithstanding the execution of a considerable amount of extra work beyond that contemplated in the original contract. Details of the amount of work done, and of the plant and materials employed, are given in Appendix I; and the rate of progress is indicated by a diagram (Fig. 1, p. 162).

Reclamation.

As the commencement of the permanent works could not be delayed till the completion of the reclamation embankment, temporary banks were formed to exclude the tide from the site of the north quay wall and graving-docks, forming the innermost works, so that these works might be carried on during the progress of the outer bank (Plate 2, Fig. 1). The banks A B and B C were soon completed by casting up the earth from each side, and the excavation inside the enclosed space was commenced. The portion B D E, however, had to be carried across a foreshore of mud, and was at a considerably lower level towards the east end, so that a good deal was washed away by the tide; and it therefore had to be carried on at several points simultaneously by a large gang of men, taking advantage especially of neap-tides; and its seaward face was pitched with chalk, as it was most exposed to south-easterly storms, and the bank had to protect the inner works for more than two years. On the completion of this bank, the excavation on the site of the north wall and graving-docks was rapidly carried on, the material being tipped to form protecting banks along F G and H I. These banks settled down into the soft muddy foreshore, and spread out a good deal laterally, and were also exposed to the

wash of every tide, so that they absorbed a large amount of material. The river embankment was meantime being proceeded with by excavating a trench, 20 feet wide and about 5 feet deep, with a Priestman steam-grab, along the line of the toe of the bank. This trench, which was carried down to hard gravel or clay, was filled with large chalk stone deposited from small vessels holding about 100 tons each. The bank was given a width of about 30 feet at the level of the river-bed; above low-water level it was roughly formed to a slope of 2 to 1 on the face; and it was intended to back it with solid clay or other hard material. The western tip of clay could not, however, be carried across the muddy foreshore to the outer embankment; the advance made by day was lost at night, and the foreshore rose gradually till it overtopped the chalk bank, when more chalk had to be deposited to prevent the mud from flowing into the river, which increased the height of the chalk bank without a corresponding increase in strength. Endeavours were made to prevent the spreading of the tip by sinking several old barges, filled with chalk, in the line of the tip, but the barges floated along in the mud; and in October, 1881, when the tip-head was 100 feet from the outer bank, a portion of this bank, which had been raised 15 feet above low-water, slipped forward. A solid chalk embankment was then decided upon, 80 feet wide at the river-bed, with a deep dredged trench, 40 feet wide, to receive the toe; and the chalk was backed with stiff clay for 30 feet in width. This watertight bank was executed without difficulty; and its seaward face was pitched with Bramley Fall stone, to protect the chalk from disintegration by the weather (Plate 2, Fig. 4). The portion that had slipped was secured by two rows of sheet-piling, 20 feet apart, with large chalk filling between them, the piles being 36 feet long, with strong walings firmly strutted and lashed with chains. The connection between the western tip-head and the outer bank was also made with chalk rubble; and the middle tip, H I, was carried on in the same way to join the eastern side of the cofferdam. The main embankment, and a cofferdam in front of the lock-entrance, were sufficiently completed in June, 1882, for the tide to be excluded from the second reclamation, when the excavations within the reclaimed area were at once utilized for forming the third, or eastern, reclamation bank D K; and the tide was finally excluded from the whole site in November, 1882.

The cofferdam was segmental in form, with a radius of 255½ feet and 461 feet long, constructed of two rows of piles, 6 feet apart, with clay puddle between, the piles being 50 to 60 feet long, and driven about 33 feet into the ground, the main piles reaching

down to 54 feet below high-water. It was commenced in July, 1881, and completed in June, 1882, and contained 67,702 cubic feet of timber [1] (Plate 2, Fig. 3). Five sluice openings were made in the cofferdam to allow the tide to flow in and out till the completion of the dam. The connections between the ends of the cofferdam and the embankment were to be made watertight by a seal of clay round the end of the dam, keyed into the clay backing of the embankment; but, on the western side, some runaway wagons deposited their loads of chalk into the puddle trench which was being formed round the dam, and as this chalk was not fully removed, owing to its low level, the water leaked through in several places near the junction. This leakage was stopped by excavating a trench outside the cofferdam, removing all the chalk, and filling the trench with fresh puddle; and this difficult operation was also carried out at the eastern junction for overcoming a similar leakage. The maximum deflection of the dam was 3 inches, from external pressure at the centre.

As soon as the cofferdam was closed, and the second reclamation made secure, the inner bank, A B, was broken through, and the excavations were rapidly pushed forward with the object of reaching the lock; and work was also commenced at the southern end of the lock, and several other places (Plate 2, Fig. 1).

Excavations for the Dock.

The southern portion of the site of the dock was covered with warp, or river mud, which was stiff and sticky inshore, but softer further out, and though drying on the surface when reclaimed, remained quite soft below for a long time (Plate 2, Fig. 5). This mud varied in thickness up to 27 feet; and below it, beds of warp, sand, gravel, clay, and peat were met with in no definite order. The roads over this thick bed of soft mud had to be laid with two, and sometimes three, thicknesses of close timber and sleepers; and the passage of a locomotive over these was accompanied by a distinct undulation.

The contractors were allowed to use the hydraulic engines of 300 I.HP., which were afterwards to serve the dock; and they availed themselves of this power for excavating with hydraulic navvies, for hydraulic jiggers working inclined barrow-roads, for pile-driving, crane-work for masonry, and other purposes. Two hydraulic navvies were used on the works (Plate 2, Fig. 17), of

[1] The piles were mostly pitch-pine or Memel; and several of the main piles required thirty to forty blows of a 1-ton monkey, falling 8 feet, to drive them 1 inch.

which a description is given in Appendix II, together with some particulars about the other hydraulic plant. Hydraulic power possesses the following advantages in the construction of works:—It is more rapid in action than steam-power, more reliable, and less subject to derangement; is pleasanter in working and less noisy, and never unduly strains the machinery; the machines also need considerably less repairs, and as they do not require to be provided with coals and water, less weight has to be carried on soft roads, or at the back of newly-made walls. As, however, a contractor would hardly undertake to lay down the necessary plant for a temporary purpose, the employment of hydraulic power for works of construction must be regarded as exceptional, though it was used with much success in promoting the rapid progress of the Alexandra Dock.

Electric light was employed at night for expediting the works, and a good deal of excavating and some pile-driving were done by its aid; six 3,000-candle, and ten 600-candle, arc-lamps were used. The larger lamps were mounted on tall masts, in situations where they would be required for a considerable time; and the smaller lamps were put on poles, from 12 to 15 feet high, which could be easily shifted from place to place.

Dock-Wall Foundations.

The dock wall was designed to be founded 12 feet below dock-bottom, at which depth it was anticipated that hard clay would be found; and at the first foundation excavated at L (Plate 2, Fig. 1), boulder clay was reached 4 feet above the required level. Proceeding westwards, however, the clay varied very much in level, dipping sometimes with a slope of 1 in 4 and rising again 60 to 80 feet further on, the dip being filled with silt or very fine sand, which had to be excavated to an extra depth, reaching sometimes 9 feet; and sometimes it dipped almost vertically 6 or 8 feet. To expedite the work, the contractors had commenced the timbered trench for the wall nearly 10 feet above dock-bottom, so that the extra depth was a source of much difficulty, necessitating narrowing the trench in putting down the timbering, and endangering the sides by the washing in of sand. Eastwards the clay was at a good level under the north wall, which could be founded at the intended depth; but in the last 300 feet of the western portion of the wall, the clay, after running 5 to 6 feet below the desired level, dipped suddenly almost vertically; and on excavating the sand to a little lower level, water boiled up and the sides soon began to sink. A boring sunk in the trench showed that 12 feet would

have to be excavated to reach the clay, which would have risked the collapse of the trench. Accordingly it was decided for the future to enclose the foundations between sheet-piling, tongued and grooved, and to found the walls at the designed level, unless clay could be certainly reached about a foot deeper (Plate 2, Fig. 6). Large chalk was thrown into the enclosed space until a firm bearing was obtained, and the concrete was then deposited. The portion of the north wall on this site was finished and backed up for nearly three years before the water was let into the dock, and showed no sign of settlement or displacement.

To determine the requisite length for the sheet-piling, borings were taken as the excavations were opened out, showing that the clay along the site of the west wall was, on the average, over 6 feet below the foundation level; and half piles grooved and tongued, 30 to 35 feet long, were driven to penetrate 3 feet into the clay bed. When the excavation was further advanced, no delay was caused by deferring the sheet-piling of the trenches till the excavation was carried down to dock-bottom, which enabled piles of only 20 to 24 feet to suffice. The sheet-piling both enclosed the foundation, and also prevented the chance of a head of water removing the sand from under the wall. Plain sheeting was after a time substituted for grooved and tongued sheeting, on one side of the trench, for the west wall foundations.

Along the site of the east wall, the clay was at a suitable level; and the foundations were carried down to it in a trench timbered in the ordinary manner.

The site for the graving-docks was enclosed with grooved and tongued sheet-piling driven into the clay, and the work commenced at the designed levels irrespective of the nature of the stratum reached. The masonry of No. 1 Graving-Dock was laid on a very dry foundation of clay, peat, and silt. No. 2 Graving-Dock, being deeper, was carried to a lower level; and the masonry was laid upon a bed of 3 feet of Portland-cement concrete (Plate 2, Fig. 16).

The chimney-shafts of the engine-houses, and the accumulator towers, were built upon a foundation of Memel piles, 30 feet long, covered with a double timber platform. The piles were driven to a resistance of $\frac{1}{2}$ inch under a 1-ton monkey falling 10 feet, and were subjected to a maximum load of $15\frac{1}{2}$ tons per pile, which, according to diagrams made by the Author,[1] would give a factor of safety of 4.

[1] "Engineering," vol. xxvi. 1878, p. 141.

Lock-Foundations.

During the progress of the reclamations, the mud accumulated to a great extent upon the foreshore, reaching a thickness of $7\frac{1}{2}$ feet just behind the dam; and as it was too liquid to excavate in the open, the Contractors determined to build the side walls of the southern end of the lock near the cofferdam in deep trenches, so as to make a commencement before the excavations in the dock could be extended to the northern end of the lock. The foundations of the lock were designed to be laid $48\frac{1}{2}$ feet below high-water spring-tides, or $32\frac{1}{2}$ feet below the level of the mud (Plate 2, Figs. 8, 9 and 10). Piles, 40 feet long, were driven at the back of the trench, and half timbers in front. In the eastern trench, the clay was found at a very suitable level; the trench was excavated with a remarkable absence of water, and the foundations were laid most satisfactorily. In the western trench, the clay was much lower, 51 feet below high-water spring-tides, or $2\frac{1}{2}$ feet deeper than was anticipated; and a "blow" occurred at one point, which was promptly remedied before any extensive disturbance could result. An iron pipe was placed in the hole, and surrounded with chalk rubble, filling the hole to the surface-level of the clay, which was then covered over with Portland-cement concrete in bags, upon which the foundation concrete was laid. The water at first brought up a good deal of fine silt; but eventually, when the concrete had set, it flowed away quite clear through the pipe, and as the masonry was built up, it was led away by a horizontal pipe to a sump in the invert, thus keeping the vent open till the last. One or two other "blows" in this trench were similarly dealt with. Though there was a slight periodic variation in the levels of the water in the stand-pipes, implying some connection with the tide, yet the actual water-levels in the pipes were very dissimilar, so that practically only the water in the strata themselves had to be dealt with. The cofferdam was perfectly tight, and being driven into the clay, effectually cut off the river water, though within 40 feet of the work, and 51 feet above the bottom of the trench at high-water. As it was impracticable to drive sheeting in the deep trench so as effectually to shut in the running sand overlying the clay, the whole of this trench was excavated to the clay.

Meanwhile the ground had been opened out at the northern end, and the sheet-piling for the trenches of the side walls was driven from the level of the dock-bottom. The first length of the foundation at the north end of the west trench was being prepared on the

8th of April, 1883; the material excavated was remarkably dry, and the clay was reached at a somewhat low level and running irregularly across the trench, when, during the evening, the bottom of the trench suddenly began to heave, and soon the water burst up in two or three places and rapidly filled up the trench, mastering the pumps. Though additional pumping-power was provided, the impossibility of pumping out the water to the required level soon became apparent, not only on account of the great volume of water to be dealt with, but because of the large amount of extremely fine silt brought up with it from below the bed of clay, which was thus gradually undermined, so that the sides of the timbered trench settled very much, and large holes appeared in the adjacent ground, forming fresh exits for the water from below, whilst the material was brought up into the trench through the main blow-hole. These holes were staunched by tipping clay-puddle mixed with stable litter, straw, and bags loosely filled with Portland-cement concrete. Soundings showed that the bottom of the trench was covered with a layer of silt, $5\frac{3}{4}$ feet thick; while a rod could be put more than 40 feet down the blow-hole. The total collapse of the trench was threatened, and strong lacings were inserted, while the centre piles and strutting were partially suspended by long beams thrown across the trench. Accordingly, the pumping was reduced to the amount necessary to get in a piled foundation for the side walls at the highest possible level. The holes were filled up with chalk, and the whole area also was covered with it, in order to intercept as much as possible the silt brought up by the water. Bearing-piles were then driven between the network of temporary timbering, connected at the top by whole timber caps, on which a double thickness of elm planking was laid, forming the foundation of the inner gate-recess wall and the heel-post stone (Plate 2, Fig. 10). The timber platform was placed as high as the level of the underside of the latter to reduce the pumping to a minimum and thereby obviate further ill effects of the "blow."

To elucidate the origin of the water in the "blows," borings were made east and west of the lock, which showed that the bed of clay on each side was over 15 feet thick; whilst at the "blow," it was only 2 feet thick. The slight daily variations of the water-level in the bore-holes were considerably later than high- and low-water; and there was sometimes a difference of several feet between the water-level in the bore-holes and in the stand-pipes of the "blows" at the south end of the trench, less than 150 yards away, which seemed to indicate the existence of

parallel watercourses below the bed of clay, running probably west to east. A sump also, 12 feet square, was sunk 149 feet west of the lock, to a depth of 36 feet; and a quantity of chalk was thrown in to arrest the fine silt, and the water was pumped out; but though the water was kept down for some time, no alteration was observable in the water-level in the bore-holes, or in the quantity dealt with in the trench.

The foundations of the eastern trench, laid almost entirely on the hard clay, were meantime progressing satisfactorily; but the trench was narrowed at the inner gate-recess, so that if necessary, as on the western side, the heel-post stone could be set on piles driven outside the timbering. The east wall was at this time carried up about 6 feet above sill-level.

The foundations of the outer and middle gate platforms and invert were excavated in bands about 20 feet wide, alternate bands being timbered; and after the masonry had been built to a sufficient height, the intermediate bands were excavated without timbering. The side walls at the southern end of the lock had been built up in the deep trenches to 45 feet in height, resting on a base of only 15 feet, and, being weighted behind by the heavy mud of the foreshore, they were in a precarious state while the excavations for the foundations of the invert were being made. These foundations were accordingly excavated in very small areas, and cement concrete was substituted for rubble masonry to expedite the work, which was accomplished without accident.

The principal difficulty being anticipated at the inner gate platform, it was proposed to excavate the foundations in small areas enclosed by half-timber, grooved and tongued, sheeting; but after driving a short length of sheet-piles, 25½ feet long, transversely, and two or three gauge piles in a longitudinal direction, some "blows" occurred at the surface, which was a little above dock-bottom, and considerable quantities of water came up. In a short time several large holes were formed, and some of the sheeting sank down and disappeared. Cast-iron pipes were driven as deep as possible into the two principal springs, and in one of these the water subsequently rose 14 feet above dock-bottom, and remained at this level, indicating the upward pressure at this point. Clay puddle was tipped into the large holes and well trodden in, one hole alone absorbing several hundred cubic yards of puddle. The extensive area of the disturbance was manifested by the cracking and settling of the east and west dock walls at certain points; and the whole of the work at the northern end of the lock seemed in jeopardy. The continued flow of water, highly charged with silt,

was likely to lead to further injury, whilst 14 feet of excavation remained to be accomplished for the foundations under the sill as designed. To reach the origin of the disturbance, it was clearly necessary to carry the sheeting lower down; and accordingly pitch-pine piles, not less than 14 inches square and 50 feet long, grooved and tongued, were driven[1] so as to enclose the principal blow-holes and disturbed places, and effectually cut off the flow of water into the foundations; and the excavations were made, and the foundations completed, without the slightest appearance of water. The roller-path stones and sills were laid upon platforms of elm carried on bearing-piles. The discharge through one of the blow-hole pipes was stopped; but the water continued to flow through the other until the pipe was closed, the day before the water was let into the dock. While the sheeting was in progress, another spring appeared eastwards of the east wall of the lock. This hole was filled with puddled clay and chalk, as in the previous cases; and eventually the water flowed out free from silt till the works were finished. The dock wall on the east side, as well as the side wall of the lock, settled nearly 14 inches; and a small portion of the dock wall had to be pulled down and rebuilt. The dock wall on the west side, which was furthest from the disturbance, settled 5 inches. The remaining piece of the lock-invert, between the piling and the finished work, was successfully put in without enclosing it within sheeting, bearing-piles only being driven under the sills, heel-posts, and roller-paths. The whole of these foundations were rendered secure in September, 1884, seventeen and a half months after the occurrence of the "blows."

The lock is 85 feet wide and 550 feet long (Plate 2, Figs. 2, 9, 10, and 11), and it has three pairs of gates, being subdivided by the middle pair into two locks, 325 and 225 feet in length, which enables the lock to be used for moderate-sized vessels for long periods before and after high-water without a great loss of water, a point of much importance as the water-level in the dock is principally maintained by pumping from a fresh-water stream. The gates are of green-heart, and segmental in form, with each leaf

[1] Straight piles only of the best quality were used; and though over two hundred piles were driven in the sheeting, many of them requiring several thousand blows to get them down to their full depth in the silt, only two or three defective piles were sufficiently damaged to require drawing, which amply demonstrates the suitability of pitch-pine for hard driving. The groove was taken out of the solid pile, while, to prevent waste of timber, the tongue piece was fastened on, being placed in a notch made the whole length of the pile, and fastened on by 6-inch spikes.

constructed in three panels; and they were built on the works (Plate 2, Figs. 12, 13, and 14). There are no sluices in the gates, the filling and emptying of the lock being done through 5-foot culverts, two pairs of which are built in the lock walls, at each sill, at low-water level (Plate 2, Figs. 8, 10, and 11). On one side of the sills these culverts open into the gate-recesses, and their inlets are closed by external paddles of green-heart resting against granite faces, and worked by hydraulic power. The gates, capstans, and swing-bridge, are moved by hydraulic machinery supplied by Sir W. G. Armstrong and Co. As the two outer sills are 1½ foot deeper than the inner one, the gates are made to correspond; and whereas each leaf of the inner gates weighs 170 tons, each leaf of the outer pair weighs 176 tons. The roller-path is of cast-steel, most carefully and accurately bedded on granite; and the gates were moved upon their roller-paths after erection without injury, though each gate, when out of water, put a load of 100 tons upon its roller.

Dock Walls.

The wall was designed to be constructed with ashlar stone on the face, and rubble chalk backing from dock-bottom up to 14 feet below the coping. A strike, however, of the masons whilst the work was in progress led to the substitution of Portland-cement concrete for the ashlar and chalk, at the same rate per lineal yard of wall. The upper portion of the wall, 14 feet high, was built as designed of stone, with ashlar facework projecting 6 inches beyond the lower part of the wall, thus forming a fender, and granite coping (Plate 2, Fig. 6). By the partial substitution of concrete, the construction of the dock was much expedited, as both classes of wall could be carried on at a maximum rate. Iron pipes were built into the wall at two levels, so as to provide weep-holes at intervals of about 75 feet all round the dock; and a rubble drain, 2½ feet square, was placed along the back of the wall. In some places water was constantly running through these weep-holes after the walls were backed up, and thus the walls were preserved from undue pressure at the back. The chalk used for backing, obtained chiefly from the Lincolnshire Wolds, is hard, and is durable when not exposed to frost; but during construction in the winter months, the chalk had to be protected by a thin casing of Bramley Fall rubble at the back, for fear of injury before the backing could be carried up. The masonry was set by hydraulic cranes, or by travelling steam-cranes, lifting 3 tons, provided with specially long jibs, so that they could set the lower portion of

the wall; and the walls were then filled in behind, and the cranes raised to this high level to set the upper 14 feet. The masonry was set in lias-lime mortar, made with limestone brought from Lyme Regis and burnt on the works. The Portland-cement concrete was 7 to 1 at the back, containing large stones placed by hand; and the face was finished with fine 5 to 1 concrete.

No failure or slip occurred in the whole 2 miles of wall, except near the lock, as already mentioned; and the only serious settlement occurred at the head of the western jetty, which was clearly attributable to a disturbance under the clay, probably due to the "blow" at the lock. The wall there had been raised to coping level, and backed up to within a few feet of the top for some time, when cracks appeared on each side of the jetty head, and extended from top to bottom, water coming through the cracks at the bottom, and also in large quantities alongside the sheet-piling extending round the toe of the wall. The cracks gradually opened to a width of about 1½ inch. As the foundation had been laid on a hard, dry, clay bed, it is probable that the clay bed was undermined by the disturbance produced by the "blow" at the lock. The filling at the back of the wall was removed down to the original surface; and as the dock was filled with water, the wall was backed up with ashes. The masonry facework was cut out at the cracks, which were then filled up solid with cement concrete.

Graving-Docks.

The graving-docks were constructed of masonry throughout (Plate 2, Fig. 2, 15, and 16). The larger dock is 550 feet long on the blocks, but could take a vessel of somewhat longer keel; its entrance is 65 feet wide, and, having a depth of 21½ feet at high-water ordinary spring-tides, it is available for large vessels. The other is 500 feet long, with an entrance 60 feet wide. The pumping station for emptying the docks is placed between the two docks; and there is a 5-foot pipe culvert leading from the Holderness drain into a chamber at the north end of the building. On the opposite side of this chamber is another culvert, fitted with a sluice valve to shut off the waters of the Holderness drain at any time; this culvert, in passing to the pump well, is joined by a transverse culvert from each graving-dock. There are two vertical Gwynne centrifugal pumps with 4-foot suctions, worked by direct-acting horizontal condensing engines, supplied with steam from six Lancashire boilers with Galloway tubes; and each pump, making 145 revolutions per minute, throws 31,250 gallons per minute with

a maximum difference of level of 21 feet. Each engine can be coupled up to either pump, so as to provide against a stoppage of pumping in case of a break-down. A single pump empties the larger dock, from high-water spring-tide level, in three and a quarter hours; and the two pumps working together can raise the water in the dock 1 foot in three and a quarter hours. A smaller centrifugal pump, with 6-inch suction and an independent vertical engine, is provided for drainage. The culverts leading from the graving-docks are closed with double-faced green-heart paddles worked by hydraulic power; and the graving-dock gates are worked by hand.

Dredging forms a heavy charge in the maintenance of the original Hull docks, owing to the free access into them of the very muddy waters of the Humber, near high-water, for two or three hours each tide, and at tides approaching springs occasionally making up 3 feet difference of level. The deposit introduced into the docks from the Humber amounts sometimes to 1,250,000 tons of mud in the year, necessitating the employment of a large dredging plant for its removal. To obviate as far as possible the necessity for this dredging in the Alexandra Dock, fresh water is pumped up into the dock from the Holderness drain to maintain its level. This drain is a fresh-water stream, draining a large portion of the Holderness division of Yorkshire, which has its outfall adjacent to the Alexandra Dock; and the pumps can raise 14,500,000 cubic feet of water from it in twenty-four hours, thus greatly benefiting the drainage of the surrounding low-lying country, as well as reducing the cost of maintenance of the dock.

Entrance Channel.

The extreme southern boundary of the river embankment is fixed by the line of river improvement laid down by the Humber Conservancy Commissioners. The navigable channel of the Humber approaches close to the northern shore in front of Hull; but at the Alexandra Dock, the northern edge of the deep channel was 960 feet from the outer lock sill. The channel there is 35 to 40 feet deep at low-water spring-tides, having an almost vertical face in places on its northern side, the depth increasing suddenly from 5 to 30 feet, owing to the scour of the tidal current against this side, the channel having been eroded by it out of the hard clay of the "Hebbles," a shoal extending $\frac{1}{2}$ mile above, and 2 miles below the Alexandra Dock. The original surface of the foreshore and river-bed, and the deepening effected by the dredging-operations previous to the opening of the docks for traffic are shown in Plate 2, Fig. 5; and

the area of the channel as completed, and also the proposed ultimate channel are shown on Plate 2, Fig. 2. The Hebbles shoal is mostly composed of very hard boulder clay, with large boulders reaching up to ½ ton in weight, and smaller stones strewn over the surface; and beds of peat were also found, with portions of trunks of large trees, and quantities of hazel nuts. An extent of 35 acres of this shoal has been dredged away, from an average depth of 3 to 6 feet, down to 12 or 14 feet at low-water spring-tides. Considerable accretion was constantly going on during the progress of the dredging, especially before the work was sufficiently advanced to promote tidal scour, and during five months of cessation of work.

At first the dredging was carried on with a double-ladder dredger of 30 HP., a single-ladder dredger of 40 HP., and a grab dredger; but the two first could not dredge in greater depths than 25 feet. After the delay caused by the stoppage in 1884, it became evident that these machines could not complete an adequate channel by July 1885, when the dock was to be opened for traffic; so a single-ladder dredger of 45 HP., hired from the Furness Railway Company, was set to work, in March 1885, on the very hard material at the lower end of the shoal, and proved very suitable; and being able to dredge in 30 feet of water, it could work almost continuously. One of the 60 HP. double-ladder River Tyne dredgers was also hired, and started on the upper, or western, portion of the shoal. The grab dredger worked in the trumpet-shaped entrance, whilst the other four dredged in the tide-way; and the entrance channel was completed by July 16th, 1885, when the first steamers entered the dock. The outer portion of the channel fairly maintains its depth; but a good deal of deposit occurs further in, which is removed by dredging during the few hours in each tide that it does not interfere with the passage of ships. The grab and single-ladder dredger only just suffice to maintain the entrance at its proper depth; and until the Hebbles shoal is removed to the extent originally contemplated, dredging will be necessary for maintenance.

The method of disposal of the material dredged from the Hebbles shoal was a matter of considerable difficulty, as the river authorities required that it should be either carried out to sea some miles beyond Spurn Point, or that it should be deposited on the Company's property behind the embankments. The first method would have been tedious and costly, and would have involved large additions to the towing and hopper plant, and was not adopted. The material dredged in the earlier stages of the work was deposited

behind the main river embankment, but this site was not available during the last six months of the work. The material was, accordingly, disposed of partly in filling up behind the quay walls, and partly in embanking a further portion of the foreshore, eastwards of the dock, which the company purchased under their Act of 1882, thus providing a site of about 130 acres where large quantities of the dredged material could be deposited, with great advantage, for raising the level of the foreshore. The chief portion of the dredgings was deposited there during the last six months of the work, as the hoppers could be towed over this site during the greater part of each tide. About 101,000 cubic yards of the dredged material were used for filling up deep holes around the quays. To carry the material from the barges to the quays, a stage was constructed at half-tide level, on the eastern slope, large enough to receive six barges at one time, which were floated over when the tide was high enough, and moored in two parallel rows. A train of wagons was run down on a line of rails between the barges, as soon as the tide had fallen sufficiently, into which the material was loaded from the barges. The process, however, was slow, and detained the barges a whole tide.

Timber Wharfing.

A timber wharfing lines the sides of the trumpet entrance to the lock, and is returned for a length of 300 feet up and down the river, along the Humber Conservancy line; it is constructed in bays, 10 feet apart generally, and 3 feet only at the corners, braced transversely and longitudinally, and covered with a 5-inch decking (Plate 2, Figs. 2 and 7). The river-bed in front of the wharfing had been dredged away to about 40 feet below the top of the piles, so that the piles, which were 61 feet long in front and about 15 inches square, penetrated only about 20 feet into the ground. Grooved and tongued sheeting, 25 feet long and 8 inches thick, was driven all along the front, the top being just above low-water; this sheeting, like most of that in the dock, was driven "simultaneously," all the piles of a bay being pitched together, and driven about 6 feet at a time till the whole bay was driven down, which ensured the tongues being properly engaged in the grooves, so that the sheeting was very close and tight.[1] This sheeting held up the material at the

[1] The wharfing was constructed from a staging on piles driven by engines on barges. The sheeting was driven by engines, with telescopic leaders, travelling on the staging at a high level.

back when the river-bed was deepened in front. During construction, the mud accumulated so rapidly in the recesses behind, that whole-timber sheeting had to be driven at the back to retain the mud, so that the soil between the piles might be excavated to enable the cross-bracing to be fixed at as low a level as possible. The recesses behind the wharfing have not as yet been filled; but if more land should be required there, it would be expedient to remove the mud between the front and back sheeting, and fill up the space with chalk, hand-packed above the water-level, so as to make the wharfing serve as a retaining wall.

Equipment.

The storage accommodation at the opening of the dock consisted only of three corrugated-iron sheds and a two-storied brick warehouse, affording altogether a storage capacity for 70,000 quarters of grain. To supply the want of more warehouse room, which was at once felt on the opening of the dock, a two-storied brick warehouse, with extensive bacon-cellars below, and a three-storied warehouse and several sheds were built, making the total storage capacity 138,000 quarters, and cellarage of 168,000 cubic feet.

The quays were also equipped, at the opening of the dock, with twenty-three travelling hydraulic cranes to lift 1½ ton, one 10-ton fixed hydraulic crane, ten movable jiggers, twelve small wagon capstans, and two 19-ton wagon-hoists for coaling, which were all supplied by Sir W. G. Armstrong and Co. These have been since supplemented by two travelling 5-ton hydraulic cranes, one 25-ton fixed steam-crane, and one 100-ton fixed steam-crane the last-named being constructed by Messrs. J. Taylor and Co., of Birkenhead.

A portion only of the extensive space on the north side of the dock has at present been utilized for coal sidings, on the system so successfully adopted at some of the South Wales ports. The loaded wagons pass from the sidings, placed 6 feet above the quay, down a gradient of 1 in 100, to the quay-level, and on to the hoist; and, after being lifted to the required height and tipped, the empty wagons leave the hoist at the level of 17 feet above the quay, and run down a gradient of 1 in 70 to the sidings from which they came when full. There is thus a continuity and absence of interference in the various operations, which greatly expedite the shipment of coal. With good wagons and a suitable vessel, thirty wagons have been discharged at one hoist in an hour; and during a shorter period, the maximum rate has equalled thirty-three wagons, or 280 tons, per hour.

Concluding Remarks.

In the first twelve months after the opening, up to the 30th of June, 1886, over 357,000 tons of shipping entered the dock; and the maximum number of vessels in it at one time was forty-three. In the twelve months ending the 30th of June, 1887, 628,738 tons of shipping entered. Much of the shipping is of the largest class frequenting the port, including steamers with a draught of $26\frac{3}{4}$ feet, which have passed through the lock at dead neap-tides—an impossibility previously at Hull.

The dock was designed and carried out by Mr. James Abernethy, Past-President Inst. C.E.; and Messrs. Oldham and Bohn, MM. Inst. C.E., were the Acting Engineers at Hull. Messrs. Lucas and Aird, Assocs. Inst. C.E., were the Contractors, and Mr. William Colson, Assoc. M. Inst. C.E., was their agent. The Author was the Resident Engineer; and he takes this opportunity of acknowledging the valuable assistance rendered him by Mr. G. N. Abernethy, M. Inst. C.E., Mr. H. W. Abernethy, Assoc. M. Inst. C.E., and Mr. G. Fitzgibbon, Assoc. M. Inst. C.E., who were associated with him on the works.

The Paper is illustrated by 28 sheets of tracings, from which Plate 2 and the Fig. in Appendix II have been made.

APPENDIXES.

APPENDIX I.—Amount of Work done, and Materials and Plant employed at the Alexandra Dock Works.

Quantity.	Description.	Maximum in one Month.
3,350,000 cubic yards	Excavation	142,315
661,000 „ „	Dredging	75,256
50,000 tons	Limestone	..
14,000 „	Cement	..
400,000 „	Sand and gravel	..
70,000 cubic yards	Mortar	..
74,000 „ „	Lime concrete	26,151 cub. yds.
88,000 „ „	Cement concrete	
144,000 „ „	Chalk rubble masonry	
136,000 „ „	Bramley Fall do. do.	
15,000 „ „	Brickwork	
115,000 cubic feet	Granite	
349,000 „ „	Dressed Bramley Fall ashlar	
608,000 „ „	Rock faced do. do.	
390,000 „ „	Timber in piles and sheeting	..
92,000 „ „	„ in walings, bracings, &c.	..
293,000 cubic yards	Chalk stone embankment	22,987
1,500,000 cubic feet	Timber used in temporary work	..
60,000 tons	Coal „ „	..
31 No.	Locomotives	..
975 „	Wagons and trucks	..
37 „	Movable engines	..
42 „	Cranes	..
24 „	Pile engines	..
5 „	Steam navvies	..
2 „	Hydraulic navvies	..
150 „	Boilers under steam	..
3,500 „	Men (greatest number at any time)	..

APPENDIX II.—Hydraulic Plant employed at the Alexandra Dock Works.

The hydraulic navvy, designed by Sir W. G. Armstrong and Co., had a jib like Messrs. Dunbar and Ruston's steam-navvy. The lifting-ram and multiplying-sheaves were placed in an inclined position at the back of the machine, so that their weight might exercise the greatest counterbalancing effect when the bucket was making a cut (Plate 2, Fig. 17). The diameter of the ram was 14½ inches, and the stroke, which could be varied at will, was usually worked at 4 feet 5 inches. There were five sheaves; and the chain, on leaving the last one, passed over the end of the jib round a block attached to the bucket-frame, and was

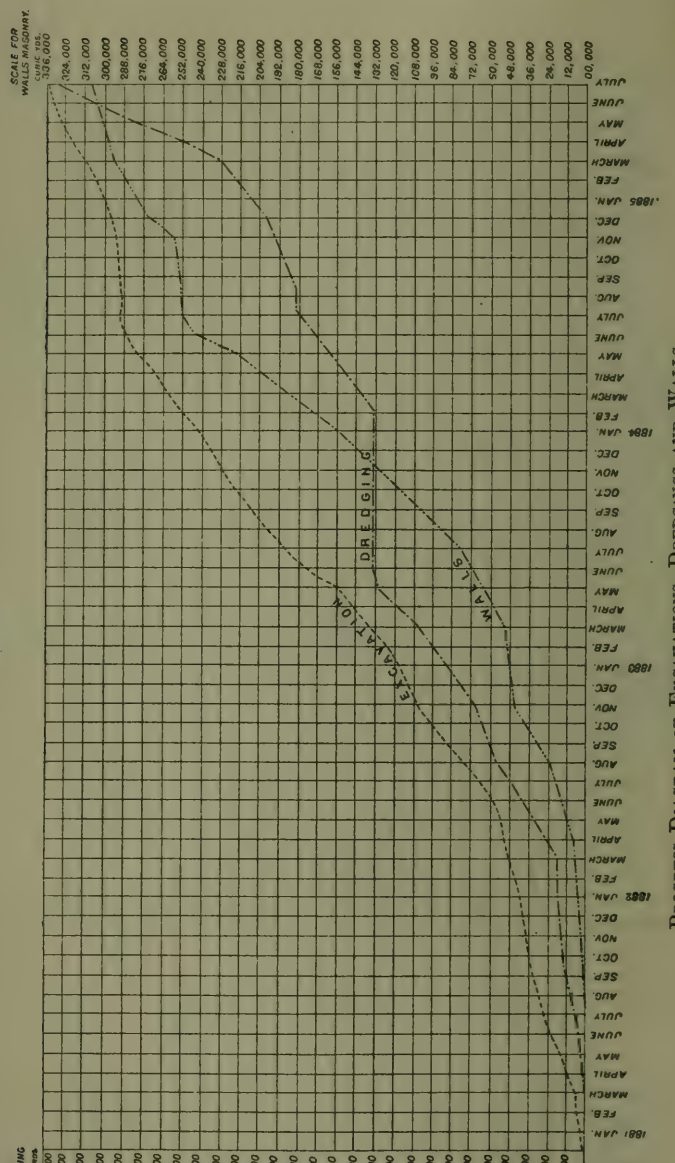


FIG. 1.

PROGRESS DIAGRAM OF EXCAVATIONS, DREDGINGS AND WALLS.

attached to the jib at the end. The travel of the ram was thus multiplied three times; and with a working pressure of 700 lbs. on the square inch in the accumulator, the maximum cutting force on the end of the bucket, allowing for friction, was about 12 tons. The capacity of the bucket was 1½ cubic yard. Two rams 4½ inches in diameter, fixed horizontally on the floor of the carriage, slewed the jib in opposite directions through the entire arc with a stroke of 3 feet. The fore-and-aft motion of the rack-beam and bucket, and the brake and releasing arrangement of the bucket, were the same as in the steam-navvy, and were controlled by a "wheelman" at the foot of the jib. The lifting and slewing were controlled by one man working two levers on an elevated platform. A small horizontal ram, placed under the footboard at the base of the jib, is connected with a rod-and-lever clutch which engages with a toothed wheel, keyed on to the front axle of the navvy, as the ram reciprocates; and thus the machine travels a few inches at each stroke of the ram. The navvy weighs about 30 tons, and is provided with screw-jacks at the corners. The connection with the 4-inch pressure pipes, laid nearly up to the machine, is made with 2-inch pipes fitted with universal joints, which allows the navvy to advance about 9 feet before adding another length of pressure-pipe. The exhaust water passes from a small tank into wooden shoots, and is led away from the cutting. The number of men required, and the method of working, are the same as in the steam-navvy. The machine can excavate 600 cubic yards in favourable ground, under ordinary conditions, per day of ten and a half hours; its speed of working, as compared with the steam-navvy, is as 13 to 10, and the ordinary repairs as 1 to 1·4. The average consumption of water for the above daily excavation, when the machine makes two lifts to each wagon of 3 yards at a deep face, is 17,000 gallons. It works with very little noise, and the gearing is not liable to be damaged when the motion is suddenly stopped by the bucket cutting too deeply or in too stiff ground; but it could not be economically worked except where the permanent hydraulic engines can be utilized for providing the power. The cost of the machine, complete, was about £1,300.

Hydraulic jiggers were largely used for lifting the excavated material in barrows about 45 feet for backing up the walls, which was accomplished much more rapidly and uniformly than with the ordinary horse road. The usual gang of men at one of the machines moved 92 cubic yards per day, with a consumption of 2,800 gallons of water. The three different sizes of machines used had rams of 8, 11¼, and 13 inches diameter respectively, with a maximum stroke of 3 feet. The length of lift is limited by the diameter of the rope drum.

The ordinary movable hydraulic crane with a long jib proved specially serviceable, when placed on a high wall, in lifting and jibbing excavations from dock-bottom with extreme rapidity. Thus, on one occasion, under particularly favourable conditions, with a lift of nearly 30 feet, a gang of navvies removed 27 cubic yards per man per day with one of these cranes.

[Discussion.

Discussion.

Mr. Hurtzig. Mr. HURTZIG wished to add a few words on the question of expedition. The works at the dock were carried on with almost unparalleled vigour; but a loss of several weeks would have occurred if it had been necessary to wait for the completion of the gates and various other inner works before removing the cofferdam. That contingency was anticipated by the Engineer and provided against. By the Act of 1881–2 the Company had power to build another dock to the eastward, which was to communicate with the Alexandra Dock by means of a canal having an entrance on the east side. Provision was made for a caisson stop to be placed between the cofferdam and the outer gates; and a floating steel caisson was built to enable the cofferdam to be removed while the erection of the lock-gates and the remainder of the inner works were being completed. That clearly effected a saving of several weeks. The caisson consisted of framing and plates of steel of the usual kind. It was 95 feet wide at the coping level and 88 feet at the bottom. A double keel of green-heart was passed round the caisson, which being dressed very smooth made a water-tight joint with the granite masonry. The caisson was completed in December, 1884, when the erection of the lock-gates was commenced. During the whole of the remaining six months the Contractors had ample time to remove the cofferdam, while the inner works were going on with ease. The caisson served two or three other purposes, one of them being to close the entrance to the canal to which he had referred. In the canal entrance there was also a caisson stop, and when the new dock was made, instead of having to go to the expense of building a big cofferdam the caisson would take its place. It was also available for excluding the tide in case of accident or otherwise when work was being done in the dock at a low level. Very few docks in the country were so wide as 1,000 feet. A ship 550 feet long could go across on entering without interrupting operations at the opposite quay. Although it was said by some persons that there was little difficulty in manipulating ships in a narrow dock, there was still less difficulty in manipulating them in a wide dock.

Mr. Vernon-Harcourt. Mr. L. F. VERNON-HARCOURT said that the Paper had recalled to his mind his earlier experience with regard to dock construction on the foreshore of the Humber about twenty-four years ago. In reading the Paper he observed many points of similarity. He

believed that no other place could now be found at Hull for making docks except the foreshore of the Humber. In the Albert Dock, on which he was engaged for some time, very similar arrangements were provided for carrying out the work. There was the reclamation bank in front, with a toe of chalk; there were cross banks where certain portions had to be reclaimed first; there was naturally a removal of a great deal of stuff from the banks by erosion during the progress of the works; and (as had been stated in Mr. Hawkshaw's Paper on the Albert Dock[1]) a difficulty had been encountered from the blows that had occurred at the lock. Another difficulty occurring on the foreshore was that as soon as the foreshore was enclosed at all, there followed a large accumulation of the mud with which the Humber was so densely charged; so that there was more work to do in the excavation than appeared upon the sections at first. That made it somewhat difficult to settle what the contract price should be. There was also, on that muddy foreshore, considerable difficulty in the foundations. In some of the wall foundations at the Albert Dock, sheet-piling of whole timbers was driven upon both sides, and the lower portion of the dock wall constructed in the trench excavated between; and in other cases the wall was built upon bearing piles. As far as he could judge, more difficulties had been encountered in constructing the Alexandra Dock than in the Albert Dock. It was more exposed to the sea, being farther down the Humber; it extended farther out on the foreshore, and the running quicksand was met with at a higher level. It had been stated that it was necessary to enclose a certain portion of the site of the dock before proceeding with the walls; but in the case of a dock which he had seen abroad (the ninth dock at Havre), that course was not adopted. Before the reclamation of a portion of the site of the dock from the foreshore of the Seine was finished, masonry wells, filled up afterwards with concrete, were sunk for forming the walls of the dock.[2] He saw the work in progress on two or three occasions. As in the case of the Humber, there was a great silting up on the partially reclaimed foreshore. Well-foundations were resorted to in that instance to expedite the work, as it was important to open the extension as soon as possible; but he doubted the economy of the system. The use of hydraulic machinery in the preliminary operations of constructing a dock was new to him, but he should think that it was a decidedly

Mr. Vernon-Harcourt.

[1] Minutes of Proceedings Inst. C.E. vol. xli. p. 98.
[2] "Harbours and Docks," Plate 14, Fig. 23.

Mr. Vernon-Harcourt.

good method; and it would be interesting to know to what extent it had cheapened the cost of the works at Hull. As to the question of width of lock, the widest lock at Hull before the construction of the Alexandra Dock was 80 feet; and there was no lock in the port of London that had a greater width than that. At Liverpool and Havre there were locks 100 feet in width, this provision having been made for large paddle-wheel steamers, which had become obsolete; and the latest entrance constructed at Liverpool was only 65 feet wide; whilst the width proposed for the Panama Canal locks was 59 feet. He therefore inferred that a width of 85 feet was rather more than necessary; at any rate, it was more than was considered necessary either at London or Liverpool at the present time. As to the depth, which was greater than that of any other sill at Hull, 34 feet as compared with 28½ feet below high-water of ordinary spring-tides, he thought that was a wise precaution. At Tilbury there was a deeper sill than anywhere else in the port of London; and he thought it was wise to have it as deep as convenient, because there was always a tendency in vessels to increase in draught, and it was well to provide beforehand for it. It was also an advantage for a vessel to be able to enter at any state of the tide. It appeared that green-heart gates had been used at the Alexandra Dock; and he should be glad to know their cost as compared with iron gates. There was only one disadvantage connected with them, namely, that in opening a lock for locking up, when the tide was rather low, there was a greater weight on the gates than there would be upon balanced iron gates. Iron gates without rollers had recently been substituted for the wooden gates across the 100-foot wide lock at Havre. The fresh-water supply brought in from Holderness seemed to be a very good arrangement, especially as it combined improved drainage with the exclusion of muddy water from the docks; the only objection to it being that the vessels would have to be locked in and out, instead of, as was done in London, making the levels in the basins and river the same near the time of high-water, which enabled the work to be done more quickly. A similar provision had been made at the Bristol Channel ports of Swansea, Cardiff, and Newport. The form of the dock with its jetties he considered to be remarkably good. He agreed with the Author that if a wide dock could be afforded it was better than a narrow one. But what he particularly liked was the projection of the jetties into the dock, affording a much greater length of quay, and enabling the vessels to be handled more easily. The equipment also seemed to be good. It was a great mistake not to equip docks thoroughly.

Mr. Vernon-Harcourt.

He remembered that when the Millwall Docks were first opened there was not a railway to them, there were no cranes, and no warehouses or even sheds, and the consequence was that for some time the shipping in the docks simply consisted of old vessels which had nothing to do. The Author had said nothing about the cost of the works. There were only two slight references to the subject, one being a statement that the works had been stopped for a time by financial difficulties, and the other that the dock wall made in concrete cost the same sum per lineal yard as that formerly designed. It would be interesting to know what the exact cost was; and as dock walls varied so much in thickness and height, it would be well to know the cost per cubic yard. He thought that a detailed statement of cost added greatly to the value of a Paper, much more so than a mere statement of amount of work done, to which an Appendix had been devoted. On the subject of tonnage, he lately had occasion to get out the tonnage of vessels entering various ports, and he observed that Hull had not much increased within the ten years from 1873 to 1883. Perhaps the Author would state whether the tonnage given as entering the dock in the year ending the 30th of June, 1887 (628,738 tons) really represented an increase in the trade of Hull, due to the opening of the Hull and Barnsley Railway, thereby destroying the monopoly of the North-Eastern Railway Company, or whether it was only taken off the traffic from the other Hull docks.

Mr. J. Clarke Hawkshaw.

Mr. J. Clarke Hawkshaw remarked that the same difficulty appeared to have been encountered in the foundations of the Alexandra Dock as had to be contended with in the case of the Albert Dock, and it had apparently arisen from the same cause, there being a similarity in the strata met with. The intention was in both cases to found the walls of the lock on a bed of stiff clay. Below the clay there was a bed of running sand charged with water from the chalk underneath. The chalk rose to a great height in the neighbourhood of Hull; the water, gravitating towards the river, was penned below the bed of clay, and the moment the clay was pierced the water came through it. At the Albert Dock entrance there ought not to have been any trouble with the water, because there was a great thickness of clay there, 30 or 40 feet. The only cause of its getting up into the foundations was the existence of some old bore-holes. One of the bore-holes into the foundations had been found; it was a clean round hole in the chocolate-coloured clay, and it was filled with small rounded pieces of chalk. Before the morning the water had found its way through it, and half filled the foundation with sand. In the foundation of the

r.Hawkshaw. Alexandra Dock the clay seemed to have been thinner, and the water appeared to have found its way from the sand into the foundation without the assistance of the bore-holes, as the clay thinned out in some places to only 2 feet. The lesson to be learned from such difficulties was that if, in some cases, the engineers of the day contented themselves with the foundation on bearing piles which the older engineers so often relied upon, and were not so anxious to take the masonry and concrete so low down, they would often save themselves a great deal of trouble and anxiety, and get quite as good a foundation in the end.

r. Giles, M.P. Mr. A. Giles, M.P., thought that the Author had rendered the Institution great service by the details which he had given, and by his account of the difficulties and anxieties of the Engineer in the work described. He could not help saying, judging from his own experience, and also from the experience at Hull, that engineers as a rule were not careful enough as to borings. He had a case in point at Southampton, where he had had borings taken for the dock walls every 50 feet in length. He had wished to avoid the special difficulty mentioned by Mr. Clarke Hawkshaw, of having bore-holes immediately under the wall, and he took care that the borings should be 10 or 20 feet in front. The bore-holes showed practically no sand in front of the wall, but on excavating the trenches he found a depth of 5 or 6 feet of quicksand under the wall, and he had considerable difficulty in getting rid of it by excavating down to the solid ground. When a large dock was commenced everybody was in a hurry to get it completed as soon as possible, and instead of waiting until the great bulk of the excavation was out, and then putting in the walls by ordinary means, trenches were generally resorted to for the last 20 or 25 feet. On reaching the bottom of the 20-foot trench, and when all was ready for the foundations, it was not pleasant to find a blow-hole in the middle of the site of the wall, and in the blow-hole 5 or 6 feet of quicksand. That was a difficulty which he had had to encounter, and he therefore cautioned engineers not to trust too much to bore-holes not exactly in the line of the work. The Paper was very complete in all its details, but he should be glad to have a little more information as to the cost of the dock walls, the cost of excavation, and the cost of the gates per foot. He thought that a width of 85 feet for gates at the present day was unnecessary, and that 80 feet, or even 70 feet, was wide enough. An ironclad was only 72 or 73 feet beam, and 80 feet would certainly be more than ample for the commercial marine. He was surprised to hear that vessels had been admitted

drawing 26¾ feet, which was an unprecedented depth, the depth of mercantile vessels rarely exceeding 25 feet or 26 feet. That showed, however, the necessity for deep sills; but it was well known that when there were deep sills, particularly in such a muddy estuary as the Humber, there was a great deal of trouble in keeping them clear. He congratulated the designer of the dock upon having adopted gates instead of caissons for the dry-dock. He had himself never put in caissons unless they were absolutely ordered. Mr. Abernethy would excuse him if he criticised the shape of the dock. He assumed that had it not been for the shape of the area to be dealt with he would never have designed the dock in the way described. The lock was 550 feet long, and projected 400 feet into the dock; therefore the remaining space to turn a ship out of the lock between the end of the lock and the opposite wall was only 600 feet. It would be observed, in looking at the shape of the dock and entrance, how difficult it was to berth a vessel at any one of the quay walls. At Southampton he was not adopting the old-fashioned plan of making a square dock. He had so designed the dock, that vessels coming in could berth themselves at every quay very easily. There was a width of 800 feet across the dock at its widest part, and any vessel from any quay could turn round without interfering with other vessels. The dock was being dug 26 feet below low-water of spring-tides. The great advantage possessed by vessels coming into Southampton was the rapidity with which they could run in, discharge, load, and run out again. There was also an advantage in the connection with the railway sidings. No turn-tables were needed, the curves being very easy; He wished to ask Mr. Abernethy if, with his present experience, he had to make the dock again, he would make the entrance square with the channel, or pointing down the channel? He should also like to know whether any advantage had been found from the plums, or large stones, with which the Portland cement was studded. As a matter of economy he had no doubt they were desirable; and it would be interesting to know whether there was any disadvantage connected with them.

Mr. Giles, M.P.

Sir John Coode.

Sir John Coode, K.C.M.G., said he too should be glad to have a little more information as to the cost of the works, divided under the usual heads, the cost of the graving-docks, the entrance, and the quay walls.

Mr. Shelford.

Mr. W. Shelford said he believed that the shape of this dock was very much influenced by its site. The Alexandra Dock at Hull had been working for two years; it was well supplied with water-space and with quays, and no doubt the Author would be

Mr. Shelford. able to say whether the want of water-space or the want of quay-length was likely to limit the capacity of the dock. He did not ask the question from any desire to disparage or criticise the work, but because he thought the information would be useful to other engineers in designing docks. He should be glad to know also why a width of 85 feet for the lock entrance had been adopted. In the larger graving-dock at the Alexandra Dock, which was intended to accommodate the largest vessels, the entrance was only 65 feet in width. Possibly the great width adopted by the designer was to enable vessels of ordinary size to enter side by side, so that there might be a saving in lockage. A method which was intended to meet that difficulty had been carried out in a lock in America. It was at the foot of Lake Superior, was built by the United States Government, and was undoubtedly a fine piece of work. The lock was 80 feet wide, but the entrances were only 60 feet. The intention was to pass through it two vessels at a time. Of course, in that way, economy in the construction of the gates was obtained. He thought that the Alexandra Dock compared favourably in its design with other docks which he had examined both in England and abroad. He had seen it constantly during construction, and he unhesitatingly said that in every detail it bore the evidence of a master hand. The best proof that it was a good work was that the trade entering it was increasing by leaps and bounds. Allusion had been made to the Hull and Barnsley Railway, which was an adjunct to the dock, or perhaps he ought to say that the dock was an adjunct to the railway. The capital cost of the railway was about double that of the dock. The length of the line was 57 miles, besides 10 miles of branches and junctions, and it might be compared, both in character and length, to the main line from London to Brighton. The object of the railway was to connect the great coal-fields of Yorkshire and the wealthy districts of the West Riding with the port of Hull. As the coals were worked out to the westward the depth of the collieries increased. The maximum depth was reached at South Kirby. This was the newest pit and was 634 yards deep, and there was there a magnificent bed of Barnsley coal. The bed was level at that point, and it had been proved by borings and sinkings that it rose slightly to the eastward, so that there was a regular coal-basin. The eastward half was overlapped by magnesian limestone. The railway, therefore, crossed what might be called a virgin coal-field for the greater part of its length. In order to carry out the object he had mentioned there was a large depot at Cudworth, adjoining the main line, where the traffic was collected from the different

collieries and districts served by the Midland, the Manchester, Sheffield and Lincolnshire, and the Hull and Barnsley railways, and the trains made up there ran to the Alexandra Dock at Hull, in the neighbourhood of which gravitation sorting-sidings had been provided. The line was graded against the load throughout for export traffic 1 in 264, except where it crossed the Wolds, where the gradient was 1 in 150. It had often struck him that an immense amount of anxiety and thought was consumed in the carrying out of works of that character, and yet, when they were completed, there appeared to be little to say about them. Some of the anxiety might be spared if there was more co-operation amongst engineers. In America there were road-masters' and other associations, and they appointed committees to discuss points of detail, who settled standards for general adoption, and thus saved constant repetition of the same work. In England generally there was too much exclusiveness, but in The Institution of Civil Engineers opportunities were afforded for discussing those matters in such a way as would benefit the whole profession, and he thought that the less the members kept their knowledge to themselves, and the more they ventilated it, the better it would be for the members individually, and for the profession as a body. Mr. Shelford.

Mr. J. Wolfe Barry asked if any chemical analysis had been made of the Portland cement used for the concrete in the dock walls, and whether any deterioration had been noticed in the concrete since it was placed *in situ*? In several cases it was stated that when concrete had been exposed to sea-water there had been a deterioration, but he imagined that in most of those cases the concrete had been alternately wet and dry, which, he gathered, was not generally the case in the Alexandra Dock. With regard to the width of the lock, he wished to point out that, although the lock was 85 feet wide at the coping, owing to the batter of the walls, it was not 85 feet wide at the level of the bilge of vessels, which now-a-days were built with very upright sides; it was there probably only about 80 feet wide. Mr. Barry.

Mr. J. Abernethy, Past-President, said that the shape of the dock at Hull was, of course, determined by the site, and by the formation of the foreshore. If he were ever driven to deal with a site like that described by Mr. Giles, he should probably construct a dock of something like the same form; but he did not see how any commercial advantage could be gained by a dock of that kind at Hull. If jetties were projected from any one of the walls, the facility of vessels running in and taking their berths without interruption would be destroyed. Such a dock might Mr. Abernethy.

Mr. Abernethy. be well adapted for steamers going in and out in limited numbers, but he should never adopt a form of that kind, if he could avoid it, for a commercial dock. With regard to the width of the gates, it was quite true that there were very few vessels of 80 feet beam, though there were ironclads of 70 or 75 feet beam. The object of having a width of 85 feet was that vessels of upwards of 1,000 tons might come in and berth side by side. In the Alexandra Dock, at Newport, he had made the lock 65 feet wide; it was found, after long experience, that it would have been much more advantageous to have had it of a width of 80 or 85 feet, so as to enable two large vessels to lie side by side. The object was to save water required for lockage, and the construction of additional locks. He had been asked whether, if he had to construct the dock again, he would place the lock in the position shown on the plan, or have it pointing up or down the stream? Neither one nor the other. He adhered to the form he had chosen, namely, a trumpet-mouthed embayment free from tidal currents, which enabled vessels to pass in and out and get to the lock with facility either up-stream or down-stream. In practice, steamers came in on the flood-tide, steaming gently into the lock, and they left in the same way on the ebb. The Harbour-master had repeatedly expressed his great approbation of the facility with which vessels were able to go in and out. With regard to the material of which the gates were made, he had for many years objected to iron gates, owing to the unequal pressures they were subject to, and the strains in opening and shutting, rendering it very difficult to keep them watertight. The life of a timber gate was much longer than that of an iron gate. He had seen timber gates (good English oak) eighty years old taken out of a canal quite as fresh as on the day when they were put in. His impression was that a century hence the green-heart gates of the Alexandra Dock would be perfectly sound. Some questions had been asked with reference to the cost of the dock, and the Author would no doubt be able to give particulars.

Mr. Hurtzig. Mr. Hurtzig, in reply, stated that the accumulation of mud on the foreshore of the Humber was always a serious question in works carried on at Hull. The last dock built by the Hull Dock Company was closed by a cofferdam, part of which, on the occasion of one very high spring-tide, gave way, so that the water got into the dock before it was completed. He had been previously engaged with the Dock Company on that dock, and had an opportunity of fully observing the effects of the inward and outward flow of the tide to and from the basin. The walls had been carried nearly

to the finished level. In the three months, during which the tide flowed in, a depth of 12 feet of mud had accumulated in the basin, the place having proved a regular trap. On the foreshore, at the site of the Alexandra Dock, within the reclamations, in some cases there had been an accumulation of 8 or 9 or 10 feet; but there was always a certain amount of wash which kept the mud from being finally deposited to a very great thickness. Of course the deposit had to be taken out, and it was a matter of arrangement with the contractors and engineer how it should be paid for, there being no rule about it. The Alexandra Dock was a little more exposed than the Albert Dock. It would be seen from the plan that the dock was near the last bend of the river, and there was a fetch of 14 miles, and with a south-easterly gale, there were consequently heavy seas in front of the dock. With regard to the enclosure of the walls, the question of expedition was the ruling one. The contractors wanted an area where a large force of men could be set to work. The first protection banks were put up in a week or two, a thousand men or so working on them, and when they were finished the whole force was set to work on the excavation and masonry. Sinking wells for the walls of the Alexandra Dock, would not, he believed, have been a more suitable method. He thought that there had been no appreciable effect on the cost by the use of hydraulic plant, for the excavation or for other parts of the works. The cost was very much the same whether steam was used or hydraulic plant. With regard to the width of the lock, he might mention, in addition to what Mr. Abernethy had stated, that Hull was a port at which centred a large number of inland waterways from the Lancashire and Yorkshire manufacturing districts. There was an enormous traffic by lighters, keels and small barges which could not be dealt with by a small lock. He had seen the lock crammed with lighters from end to end. The keels brought goods from the Aire and Calder and other navigations down to the dock for export to America and elsewhere. The goods were all transhipped in the docks. It was a great advantage to have a wide lock for that purpose, apart from the consideration of admitting two big ships together, and he thought local conditions, as well as shipping conditions, determined the question. Green-heart gates undoubtedly would be heavier than iron, but he did not think the effect would be appreciable in working the lock. No disadvantage had been found in working the Alexandra Dock lock. The gates were 40 feet high, and they were worked when there was a depth of 20 feet of water on the sill. With regard to the tonnage of Hull, it did not increase between

Mr. Hurtzig.

Mr. Hurtzig. 1873 and 1883 at the previous rate; indeed, between 1883 and 1884 it was decreasing, the tonnage for 1884 being 75,000 tons less than for 1883. But since the opening of the dock there had been a great addition to the tonnage of the port, though there had not been any great increase in the trade of the country generally. Last year the tonnage was greater than in any previous year, and it was still growing largely. Taking the decade 1877 to 1887, and dividing it into two periods, it appeared that from 1877 to 1884, being the period prior to the opening of the Alexandra Dock, the average annual increase in the tonnage of Hull was 15,122. From 1884 to 1887, being the period subsequent to the opening of the Alexandra Dock, the average annual increase had been 133,048 tons. There was, at the present time, something like 60 per cent. more tonnage this year entering the Alexandra Dock than in the corresponding period of last year. A great deal of the increased tonnage arose from new trades being established, and old ones extended, in consequence of the existence of the Alexandra Dock. In answer to Mr. Hawkshaw's question about bore-holes, he might state that there were no bore-holes at the site of the Alexandra Dock. Only one bore-hole was put down at the commencement. A trial pit was sunk in the centre of the dock, and it was continued by boring to ascertain the general nature of the material. No old bore-holes were encountered as in the case of the Albert Dock excavations. With regard to the system of founding masonry work on piles, and not having the foundations so low, that might apply in some cases, but not to a case like that of the Alexandra Dock lock. If the clay had been found 10 feet higher than it was, it would still have been necessary to carry the work down to the levels shown. The hydrostatic pressure under the chambers of the locks was so great that it had to be resisted by a suitable weight of masonry, and a suitable form of construction. He agreed that borings as a rule were no criterion of what would be found in the foreshore where docks were being built. They might be good at certain places, but under conditions like those of Hull it was impossible to depend upon them for information, except at the exact spot where they were sunk. The object of the graving-dock gates being 65 feet wide was to provide accommodation for ships of large size, which only went in one at a time. As to the entrance, the sills were very deep, and necessarily so, for the accommodation of the large ships that had been built at Hull for the American trade. The last ship of Messrs. Thomas Wilson, Sons & Co., was figured to draw 29 feet, the

net registered tonnage being about 3,000. It was absolutely necessary to accommodate such a firm as far as possible. The sill was at a depth of 34 feet; at high-water that would take 29 feet, but at neap-tides only 28 feet 6 inches. The deepest ship that had ever been taken out was 26 feet 9 inches. At one tide a large American liner of about 2,500 tons net register, called the "Martello," came in at high-water, and immediately afterwards the "Buffalo," a New York liner of 3,000 tons net register went out, and about two hours after high-water of the same tide a ship with 4,000 tons of coal went out, drawing about 25 feet. If ships of that kind could go in and out two hours after high-water, he thought the accommodation must be very good. To enable them to do that the entrance undoubtedly ought to be trumpet-shaped. A ship, two hours after ebb had commenced, could not come into an entrance which pointed up-stream, but could come into an entrance pointing down-stream; and in a similar way a ship approaching two hours before high-water could not conveniently enter into an opening pointing down-stream. No doubt plums in the concrete were economical, and he thought they made quite as good a foundation, if not better, than concrete without large stones. Nothing, however, had occurred to enable an accurate judgment to be formed on the point. Since the failure at Aberdeen, he had had the whole face of the walls carefully examined by a diver, and there was no indication of the concrete perishing. The walls were constantly in contact with sea-water, and were liable so far to the conditions prevailing at Aberdeen. There was also at Hull a graving-dock, built by the Hull Dock Company of Portland-cement concrete, which was opened in 1881, and it had not shown the slightest sign of perishing. It was sometimes full and sometimes empty, and therefore suffered from the effect of that condition, whatever it might be. There had been no chemical analysis made of the cement at the Alexandra Dock. The cost of the Alexandra Dock at Hull, he thought, compared favourably with the cost of other docks in the kingdom, the rate per acre being considerably lower than an average of other docks. The gross cost of the works was £1,355,392, or £29,147 per acre, including two graving-docks and equipment. Without equipment the cost was £21,450 per acre, which he did not consider an out-of-the-way figure. Anything under £30,000 an acre was generally reckoned cheap. The total cost of the walls, including certain foundations for coal-hoisting, and all the subsidiary works round the walls, had been £312,224, or about £28 per lineal foot, and as the walls were sometimes 62 feet high, he thought that that sum

Mr. Hurtzig.

Mr. Hurtzig. would not be considered excessive by engineers. The gates were expensive; green-heart was dear, and the members would not be surprised to hear that the price of the gates was higher than usual for iron, pitch-pine, or other material. The cost per foot super of the lock-gates, which were 40 feet high and 50 feet wide, was 48*s*. The price of gates varied from 25*s*. to 45*s*. at various sites. The cost of the two graving-docks, including the pumping-station and pumps, which, however, were designed to perform in addition another duty, was £130,800. The cost of the lock-entrance, excluding gates, was £138,200, but this amount included all the cost of the "blow."

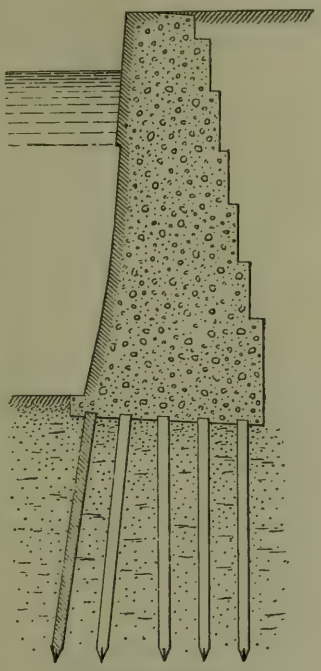
Correspondence.

Mr. Cay. Mr. W. Dyce Cay was of opinion that many of the difficulties encountered, and much of the expense incurred, in carrying out these works, might have been saved by trusting from the beginning to piles for forming the foundation, instead of trying to carry down solid concrete foundations to the clay stratum, which itself was not very secure. In his experience of reclamation embankments, he had found it a good plan to carry a row of round tree piles along the toe of the outer slope, their heads being cut off about 1½ foot above low-water ordinary spring-tides, or at the foot of the pitching, and in front of them to place a sloping deposit of rubble. This piling held up the pitched slope above it, in case of any undermining of the toe of the bank by dredging or scour, until the rubble deposit in front was replaced. The strength and security it afforded enabled such a heavy bank of rubble and clay as was used on these works to be dispensed with. In the foundation of the dock walls, of which a length of 2 miles had been constructed, instead of the base of concrete, 9 feet deep by 20 feet broad, containing nearly 7 cubic yards of concrete to the lineal foot of wall, and involving the excavation of a deep trench 11 feet below the dock-bottom, with timbering and pumping, he should have thought it better to have carried a row of sheet-piling along under the toe of the wall (Fig. 2), and to have driven additional bearing-piles, spread over the rest of the foundation of the wall, cut off say 2 feet below the dock-bottom, where he should have covered the foundation and pile-heads with jute canvas, and deposited on it a bed of concrete on which to carry up the wall. In reference to the "blows" or bursts of water and silt, described in the Paper as overpowering the pumps, and causing considerable trouble, time,

and expense to overcome them, as well as bringing about subsidence and cracks in the work, he might mention a plan which he had adopted in a similar case, more with a view to its being kept in mind than to say it could have been used on these works. By this plan, instead of trying to overcome the water, it was allowed to rise to its natural level; the excavation was completed by dredging, and the pile-heads were cut to their proper level by divers; the area was then covered with jute cloth sunk and fastened to the piling, and Portland cement concrete deposited on it under water by skips opening at the bottom, and brought up to such a height as would keep down the water-pressure and as the works allowed. After giving it time to set, the water was again pumped out, and the work finished without further trouble. The method adopted of removing dredgings from barges into wagons had been described as slow, and it was an expensive one. He had found it a better plan to fit boxes into the wells of the barges, and to fill the boxes direct from the shoot of the dredger. The barges were taken to a wharf, and the boxes removed from them by a steam-crane; their contents were emptied into wagons, and they were then returned to their seats in the barge. If the boxes were of sufficient size, this practice became very economical. The plan of subdividing a long lock, by a middle pair of gates into two shorter locks, was considered by some persons to risk the danger of breaking a long vessel's back if it took the ground on the middle sill. Where funds admitted, it would be better to have two locks alongside—a long and a short one. When not used for locking, the larger lock could be employed as a berth. The timber wharfing did not seem to have been quite successful, as a row of whole-timber piling had to be carried along the back in addition to what was shown on the plan, and it could not be

Mr. Cay.

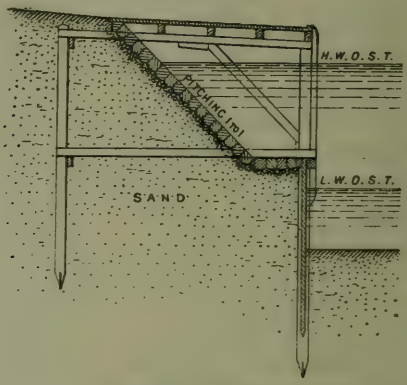
FIG. 2.



Scale 1 inch = 20 feet.

Mr. Cay. backed up without further excavation between the rows of sheeting and deposit of chalk rubble to give it weight. He had designed and used a contrivance at Aberdeen (Fig. 3), which got over some

FIG. 3.



Scale 1 inch = 20 feet.

of the difficulties by combining a pitched slope with timber wharfing, though the depth was not so great as at Hull, and it would require some modifications to make it suitable there.

Mr. Hayes. Mr. JOHN HAYES held that centrifugal pumping-machinery was without doubt the best for dock and similar purposes where large quantities of water had to be raised rapidly to moderate heights, as well on the score of economy in consumption of fuel, as of simplicity, durability, and general efficiency of engines and pumps; and it was no exaggeration to say that a large and important work like the Alexandra Dock at Hull would be rendered almost, if not quite, useless were any other system of pumping adopted. With centrifugal pumps, the first cost, as compared with others, was very small, the foundations also were less cumbersome, whilst the vibration and shaking common to all kinds of reciprocating pumps —especially of large and powerful pumps—and which would, and did wherever adopted, prove disastrous and highly injurious to newly constructed dock walls, was entirely absent, the largest centrifugal pumps being almost noiseless, and without vibration if properly constructed, even when working against maximum lifts. Another feature in their favour was the entire freedom from, or absence of, all valves, and their consequent capacity to pass or remove rough matters, as chips, shavings, dirt, mud and small stones, any of these being quite sufficient to bring most kinds of reciprocating pumps to a standstill. An incident

not without interest illustrating this point occurred some few years ago in Demerara. Two large centrifugal pumps and engines, supplied by Messrs. Gwynne and Co., of the Essex Street Works, had been fitted up and set to work in connection with drainage operations on a somewhat extensive scale. One day, after they had been some considerable time in operation, the Resident Engineer, Mr. Shekle, who had assisted in their erection, observed that the engine and pump had suddenly pulled up and then gone on again immediately afterwards. For a long time the cause was undiscovered, but eventually the remains of an alligator, 14 feet long, were found in the outlet of the pump. The reptile had passed through the pump, and had been cut into three pieces, which the Resident Engineer had stuffed, as a specimen of what centrifugal pumps would do in getting rid of obstructive debris. The alligator, in this instance, was undamaged except where parted. The pumping-machinery for the Alexandra Dock consisted of two of Messrs. Gwynne and Co.'s 39-inch centrifugal pumps, with 48-inch suction-pipes, combined with horizontal condensing-engines, one to each pump, and having a single cylinder, 30 inches in diameter by 24 inches length of stroke, a condenser and air-pump being also fitted to each engine, and placed in line with the steam cylinders. Out of the six Lancashire boilers supplied, four were capable of doing the maximum duty required, the two additional boilers being reserves, so as to enable one or more to be always laid off for cleansing or repairs. The machinery had worked very satisfactorily from starting. Mr. Hayes.

Mr. J. Horan remarked that, notwithstanding the amount of thought and the great care with which the walls of the Alexandra Dock, Hull, had been founded, it could hardly be considered satisfactory to construct a heavy dock wall practically afloat on a stratum of sand, which was permanently charged with water liable to a change of head at every tide. Under the varying conditions of the nature of the filling-in behind the walls, and the relative water-levels inside and outside the dock, anything like uniform stress over the foundation could not be hoped for, and hence one reason why walls built on this system would invariably yield more or less. But a far more serious objection arose if the probability of want of continuity in the sheet-piling, or failure to reach an impervious bed, were considered. An escape of sand, no matter how small, from below the wall only needed time to effect mischief. It was quite true that many apparent successes could be pointed to of walls founded on an enclosed bed of sand; but equally true that the most serious failures of dock-work had Mr. Horan.

Mr. Horan. been in the foundations. In the face of many more stable systems of construction, which had recognition in the use of large chalk under part of the north wall, it must ever be a matter of anxiety to the engineer how far he should, for any reasons, adopt a system which might lead to failure even at a very remote date; or, if not to failure, perhaps to the unsightly appearance caused by unequal settlement and deviation from line. An accurate comparison, up to the present date, of the amount of settlement and deviation of the walls on the different kinds of foundations adopted on the Alexandra Dock, could not fail to be of interest and utility, owing to the great extent of the work. It was to be hoped that the use of permanent hydraulic plant in dock-construction might not prove exceptional, especially now that this class of machinery was an almost indispensable part of dock-equipment. It should affect the shareholder favourably; and the assistant engineer, who struggled with his duties in the smoky atmosphere attending the construction of a large dock, would, when he came to design such works himself, see reasons for advocating the use of hydraulic plant in their construction.

Mr. Robinson. Mr. JOHN ROBINSON, of Cardiff, observed, with regard to the carrying out of embankments on a muddy foreshore, that if a mode was adopted usual in the forming of railway embankments, that was in one lift, with end-tipping wagons, the material would, if ever so good, slide away with the mud, and the heavy portion sink into it and upheave it more or less in front and at the sides, involving much labour in lifting the tip roads, besides wasting material. This appeared to be the experience at Hull and elsewhere. To try and make an embankment in such a situation with soft material would be labour in vain. At the Barry Dock works, now in course of construction, where a dam had to be made at a very important point on mud, and exposed to the flow and ebb of the tide, a temporary staging of piles was erected from which to throw down the hard material out of the wagons; in this way the dam was brought up more in horizontal layers, and without loss of material. The piles forming the staging were buried, but the top timbers were removed when the dam reached that height. This method of forming an embankment on a muddy base was both economical and expeditious. He should be glad to know what kind of wagon was used for the mud at Hull, and if any difficulty was experienced in tipping? At Barry it was soon found that good progress could not be made with end-tipping wagons, and the contractor had some side-tipping wagons constructed for mud, with the bodies mounted on three stout rockers faced with

channel-iron, which rocked on bridge-rails. The wagons only tipped on one side, and when required to tip on the opposite side were turned end for end; they held about 4 to 4½ cubic yards each of mud measured in the excavation. When a train of wagons arrived for tipping, workmen passed along the side at the back, releasing the chain- and ring-catches, and with a wooden lever or bar lifting the body, which immediately discharged the contents; this method of tipping mud he could strongly recommend. For excavating mud inside the closing dams, and particularly from wet trenches, Priestman's steam-grabs had answered best at Barry. Three grabs excavated about 1,000 cubic yards of mud in a day of ten hours, requiring three engine-drivers, three boys, three men in attendance, and eight men on the temporary lines of way. In hard or rocky marl, a steam-navvy at Barry excavated from 450 to 500 cubic yards per day, the marl being first loosened with powder; but in soft material under favourable conditions it had occasionally excavated 1,000 cubic yards per day. Some information as to lime-burning at Hull would be useful, also of the mortar-making, seeing so large a quantity as 70,000 cubic yards had been used, with the results of the behaviour of the mortar in the work. Mr. Robinson.

Mr. W. Shield observed that, in constructing a dock and other works at Fleetwood, about thirteen years ago, he, at that time being Resident Engineer in charge under Sir John Hawkshaw, experienced very similar difficulties to some of those described in the Paper, but in a somewhat less aggravated form. The dock walls were constructed in timbered trenches throughout. It was originally intended to found them at a depth of 17 feet below the dock-bottom, so as to reach hard clay; but the level of the clay surface, as at the Alexandra Dock, was found to be exceedingly irregular, and, as the overlying fine red silt was for the most part hard and compact when undisturbed, the walls were founded upon it at a general depth of about 9 feet or 10 feet below the dock-bottom. In places, however, where the foundation was bad they were founded at a lower level. These foundations required careful treatment, seeing that, although they were firm and compact when left quiet, they quickly became very unstable if disturbed or chafed in any way, even by the workmen walking about upon them. Springs were of frequent occurrence, and needed varying treatment, according to circumstances; but in general they were allowed perfect freedom until the surrounding area of foundation had been made secure, after which they were choked by concrete deposited in mass. In dealing with a spring, concrete was pre- Mr. Shield.

Mr. Shield. pared in sufficient quantity upon a platform immediately above it, and, on word being given, it was deposited as quickly as possible, the operation being performed in the course of a minute or two. When the springs carried sand with them, which was frequently the case, stable litter was freely used and weighted down, so as to filter the water and hold back the sand. Vertical pipes, carrying the water up through the concrete, were not resorted to, as experience in constructing the Albert Dock at Hull had shown that the head of water so created caused the springs to take the line of least resistance, and to break out in another and sometimes less convenient position. If pipes were used at all they should be placed horizontally, as nearly as possible at foundation level. In the foundations of the passage leading from the Fleetwood Dock to the timber pond, numerous springs caused a good deal of trouble. They threw up large quantities of sand which it was difficult to check, and the timbering began to give way and settled bodily to the extent of about 3 feet. This was, however, quickly checked by the contractors, Messrs. John Aird and Sons, by lacing it throughout with planks and suspending it by chains attached to strong logs spanning the trench. No attempt was made to stop these springs, but the passage of sand was checked as much as possible, as before described. It was decided that the springs should be driven into a corner, in a position where it was thought they could be best finally coped with. To this end the foundation was divided into sections or compartments of from 6 feet to 8 feet square. These were formed by close boarding driven about 12 inches into the bottom, the object being to prevent the sand washing out from beneath the concrete when deposited, and to secure the latter against the wash of the water. Sufficient concrete was prepared upon a platform over each compartment, as it was dealt with, to fill it to a height or thickness of from 3 to 4 feet. When all was ready this was deposited by a strong gang, almost as one mass, whereupon the spring, taking the line of least resistance, immediately appeared in the adjoining compartment only to receive similar treatment. The springs were in this manner driven to the corner at first decided upon, and, when the floor had been further strengthened by the addition of concrete, they were smothered without difficulty by a sufficiently large quantity of concrete in bulk. As the compartments were filled with concrete, the boards forming them were drawn, so as to allow the concrete to unite and thus avoid vertical joints. None of the work had, so far as he was aware, shown any sign of disturbance or settlement. The Author had not given the

reason for the omission of sluices in the lock-gates; but in view of the large amount of silting at the lock entrance they would probably have rendered good service in scouring the sills. He presumed that the proximity of the outer pair of lock-gates to the river wall was necessitated through want of room. Where the tidal current was strong, and the entrance at right-angles, or nearly so, to the stream, much inconvenience was often experienced in docking long vessels, through their sterns being acted upon by the current, while their bows were within the lock-chamber. At the South-West India Dock eastern entrance this had been overcome by the construction of substantial timber jetties projecting sufficiently far into the Thames, in bell-mouth form, to support vessels entering. The Blackwall entrance might also be mentioned as being one of convenient form. Mr. Shield.

Mr. F. J. Waring enquired what proportion the aggregate mass of the large stones which were imbedded in the concrete bore to the mass of the concrete in which they were placed? He had never used them himself, and believed there was a difference of opinion as to the desirability of doing so; the point was of considerable importance, as it was evident that in many cases a large saving could be effected in the cost of the work if their use was permitted. An expression of opinion from other engineers who had executed large works in concrete would be valuable, both as to the policy of imbedding large stones in concrete, as to their effects upon its strength, and also as to the safe proportion which their aggregate bulk might bear to the bulk of the concrete. The chief practical difficulty in using them would, he thought, be to ensure their beds throughout being in actual contact with the concrete, so as to avoid vacuities; for otherwise the concrete would lose its monolithic character, its strength would be much reduced, and it would approximate to the nature of rubble masonry of a somewhat inferior type. If the stones were of a porous nature, and especially in tropical countries, it was essential that they should be thoroughly saturated with water before being laid. Mr. Waring.

Mr. Hurtzig, in reply to the correspondence, remarked that Mr. Dyce Cay was in error in supposing that the timber wharfing was not quite successful. The row of whole-timber piling at the back was, strictly speaking, no part of the wharfing. Its only function was to hold up the great accumulation of mud, while the bracings were being attached at or about low-water level. There could have been no difficulty nor risk in backing it up after the manner indicated by Mr. Cay. This method was by no means an uncommon one, but was thought undesirable at the Alexandra Dock. In view Mr. Hurtzig.

Mr. Hurtzig. of the great depth of the wharfing at Hull—41 feet from coping to mud-line in front when dredged, being nearly double that shown by Mr. Cay—it was considered advisable to leave the back row of sheet-piling in, so that, when the backing came to be done, the deposit of chalk rubble between the two rows of sheeting would add largely to the stability of the structure without further additional cost. He thought that Mr. Horan, who had been engaged with him on the dock during its construction, was under a misapprehension of the real facts, in saying that the dock wall was "practically afloat on a stratum of sand, which was permanently charged with water liable to a change of head at every tide." The walls were founded either upon a lower bed of boulder-clay, or upon a bed of sand overlying this clay. The water in this bed of sand varied in quantity at different points, but it was never a serious matter to cope with. At the worst place, the west end of the north wall, although the bottom of the trench was alive with water bubbling up, there was no great volume of water, and no indication that a tidal or other head was influencing it. The place was, in fact, a quicksand in the true meaning of the word; an impalpable material saturated with water. The water which came from below the bed of boulder-clay was, however, of very different origin, and under very different conditions. It was truly liable to a change of head. But under the whole of the dock walls this lower bed of boulder-clay was intact, except perhaps in the vicinity of the lock where the blows took place. Therefore the risk of sand escaping from below the walls under the influence of a differential head of water was very remote. It was true that "walls built on this system would invariably yield more or less;" but Mr. Horan hardly indicated an alternative system. To what was this yielding due? The profile of a dock-wall in front must be designed with some regard to the convenience of the shipping that would use the dock; the whole cross-section of the wall must be regulated on principles of economy, so as to oppose a sufficient resisting weight to the forces tending to overturn it when backed up. But this weight must not be distributed theoretically, so as to bring a uniform stress upon the foundation regardless of all other considerations; it must be so disposed as to ensure a wall sufficiently stable, easily constructed, and capable of meeting the many and various requirements that the practical working of a dock demanded. The result was that a wall was designed with a cross-section, such that the line of the resultant thrust cut the base as near or nearer to the toe of the wall than it did to the centre of the base; consequently there was not uniformity of

stress upon the foundation, but a greater unit stress at or near the toe of the wall than elsewhere, and yielding frequently took place, but failure rarely from this cause alone. The unsightliness of a slight deviation from line was much minimized by making dock-walls on plan always curved if of greater length than about 200 feet. The greatest amount of yielding at the Alexandra Dock had been about 5 inches at the centre of a straight wall 440 feet long. If this wall had been laid out with a versed sine of 5 inches originally, the effects of any yielding would not have been unsightly, nor would there have been any apparent signs of weakness in the wall. In reply to Mr. John Robinson, the mud at Hull was not tipped, as it was impracticable to do so. It was all thrown into large wagons with side-lowering doors, and cast out again. For other material than mud, side-wagons were only used to a very small extent, at particular places, the great bulk of the work having been done with end-tip wagons, and these were of the ordinary kind. He would point out to Mr. Shield that, there being an extensive artificial approach channel to the lock, such scouring as could be effected through sluices in the lock-gates would to all intents and purposes be useless. It would merely remove the mud, or a small portion of it, from one point to another, and in either case it would have to be lifted and taken away by mechanical means. In order to be efficient as scouring agents, a number of sluices would be necessary in each leaf of the gates at a low level, and in large and heavy gates of the character of those at this lock, this would be very undesirable. The filling and emptying of the lock was done in a convenient and expeditious manner by the large levelling culverts provided in the walls; and when the mud had accumulated in the lock to an inconvenient extent, a grab dredger was put to work for a couple of days, between tides, and the mud was removed. The construction of jetties projecting into the river, for facilitating the entry of long vessels when the tidal current was strong, was out of the question at Hull; for the River Conservancy authorities rigidly enforced the observance of a well-defined limit for the erection of permanent works in the tideways. The trumpet entrance as constructed was convenient for ordinary-sized ships, and afforded sufficient support to them; while very large steamers, of 400-foot length and thereabouts, would have, at any entrance, one or more tugs in attendance for checking purposes, and would thus be independent of any support from jetties. In reply to Mr. F. J. Waring, the following rule had been observed in placing the large stones in the concrete: No stone was to be nearer any other stone than

Mr. Hurtzig.

Mr. Hurtzig. 2 feet. The stones were usually deposited by a crane, and varied in size and weight from about 4 cwt. downwards. Being always placed in soft concrete, he thought they would generally bed themselves, and that there need be no fear of vacuities. He was also of opinion that, apart from other considerations, these large stones formed a valuable means, where large masses of concrete were being deposited, as in dock walls, of bonding one day's work with that of the next.

14 February, 1888.

GEORGE BARCLAY BRUCE, President,
in the Chair.

(Paper No. 2308.)

"The Economic Use of the Plane-Table in Topographical Surveying."

By Josiah Pierce, Jun., M.A., Assoc. M. Inst. C.E.

I.—First Principles.

The plane-table, the ordinary construction and use of which are well understood, needs no introduction, being one of the most ancient of surveying instruments.

The construction of the principal types in common use will be seen at a glance on inspection of the diagrams and examples exhibited. Its wide and economic use as a mapping instrument on nearly all Government surveys, outside of whose circles it is comparatively little known and appreciated, deserves greater attention than it has received from Civil Engineers, experience having proved that within certain practical limits, plane-tabling is the most rapid, accurate, and economical of methods for topographical work of all kinds.

Briefly, the chief problem in topographical surveying is the representation of a third element, or relief, on a plane.

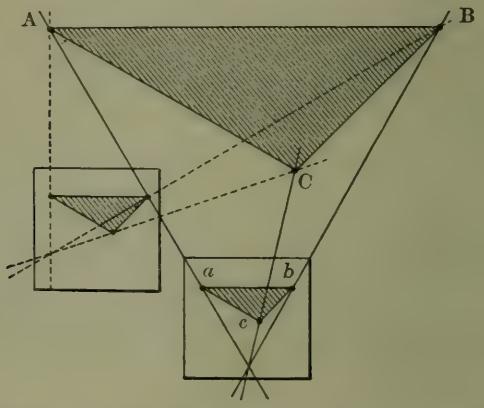
The requirements of the map are, that it should be a horizontal projection in miniature of the surface represented; that measurements taken in any direction should be made with a degree of precision limited only by the scale; and that, from any point on the map, the angles subtended by other points should be appreciably the horizontal projection of those which would be obtained between the same objects in nature. The modern plane-table, an altazimuth instrument of precision, is particularly well adapted for topographical work on all scales, for the simple reason that, by proper construction, the angular errors in the measurement of azimuth angles can be so far eliminated in practice that they may be neglected.

The fact, which cannot be lost sight of in consideration of economy, is, that the horizontal projections of existing angles are recorded graphically, free from errors of record, adjustment and plotting.

The problem of plane-tabling is simply: given a board and a ruler, construct a map. The most important geometrical laws applied in practice are those of similar figures. Three or more points being joined on the map, the requirement is that the figure thus produced should be similar to the horizontal projection of the lines joining similar points in nature.

Also, if lines be drawn from any other point on the map joining the points of this polygon, a similar point should exist in nature, where the observed angles would be exactly the same. This important condition is theoretically fulfilled when homologous

FIG. 1.



sides in the two figures are parallel (Fig. 1), and practically in field work by placing the table "in meridian" at all stations.

Frequent use is made of this property in orienting and finding one's place by three known points, commonly called the "three point problem."

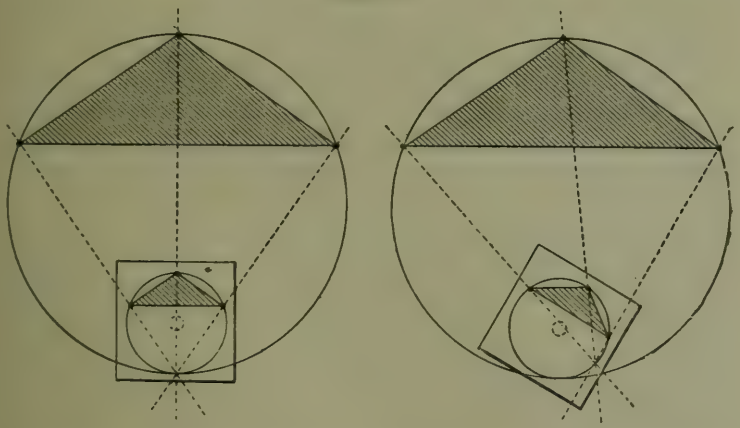
It will be impossible to describe the many cases and solutions of this more or less well-known problem, the principles of which can be most easily demonstrated mechanically.

In Fig. 1, let A B C represent three triangulation stations; *a b c* their projection on a plane-table sheet. It will be observed that in all positions, when homologous sides of the two figures are parallel, the lines joining similar points meet in a point which bears the same relation to each figure. That is, the triple inter-

section marks the station, and the board is "in meridian." In other positions in azimuth the lines produce "a triangle of error." In practice, lines are drawn on the plane-table sheet through *a*, *b*, and *c*, in the direction of the corresponding signals. Should a triangle of error occur, the problem is simply to know by inspection in which direction to turn the board to secure a perfect intersection. Since the ratio of the figure on the sheet is exceedingly small in comparison to the natural scale, the lines will be practically parallel in all positions, and the angles subtended by the sides of the triangle constant.

Hence the locus of each intersection will be the arc of a circle on which the required point lies. When the station happens to fall on the arc of the circle circumscribing the triangle, the

FIGS. 2.



problem is indeterminate, a case illustrated by Figs. 2, the triangle of error being infinitely small—there being no indication of one in any position. In other cases, an approximate position may be obtained by inspection, by observing that the point sought has been deflected from each of the lines by an equal amount of angular error—and hence the perpendiculars on these lines are proportional to the distances from the several points of the triangle. This will show whether the real point lies inside or outside of the triangle of error, and the direction in which to turn the board.

Should a second triangle occur, the point may be found at the intersection of approximate arcs joining similar points in the two triangles of error.

Since angular errors can at best be only rendered inappreciable,

the above shows that it is important to find one's place by points close at hand, and to set the table in meridian by the one most distant.

All cases of the three-point problem can be examined and demonstrated in a simple manner with the model exhibited; the ground being represented by a 6-inch Ordnance map, and the plane-table sheet by one of smaller scale. There is particularly a case of mathematical interest, if of no other practical value, viz., the problem of finding a position with an error of 180° in azimuth, the two triangles being reversed in direction.

When a triangulation exists of the country to be mapped, the plane-tabler makes immediate use of these established points. A projection is laid down on the plane-table sheet, on a given scale of the net-work of triangles, each point being shown in correct geographical position with respect to the others. When a large area is to be surveyed on small scale, provision is made for the convergence of the meridians by suitable projection.

A very wide range of opinion exists as to the number of triangulation points necessary, and a Table is given in the Appendix, showing the practice on a few of the principal Government surveys. Without entering minutely into the details of field-work, the first operation, after erecting signals, is to test the accuracy of the projection of the triangulation on the plane-table sheet. One or other of the triangulation stations is occupied, the table being set up in a horizontal plane, and the station on the sheet vertically over the point represented on the ground. To place the sheet in meridian, the ruler is laid down on the line joining the station, and the projection of one or other of the points in sight, the table being turned around in azimuth until the point sighted comes into the vertical plane of the edge of the ruler. Clamped in this position, all other points in sight should appear in vertical planes passing through the station and similar points on the sheet. In American practice, those points which will not meet this geometrical test of position are rejected until corrected graphically.

Before leaving the station, the operation of locating details is begun, by drawing a series of radial lines from the station in all directions to salient points. The same operations are continued indefinitely from other stations—the intersection of two rays on the same point being an elementary location, a third through the same point places beyond doubt the accuracy of its position. Thus, in the operation of plane-tabling, constant opportunities occur of checking locations without calculation—and the scale is ever present in all directions to control the amount of detail to

be gathered; in addition, a complete record of the area surveyed appears—advantages which are to be found in no other system of mapping. When the scale of the map is large, minute details at short range can be more profitably located by linear measurement.

The chain and off-set find no place in economical topographical surveying, the stadia rod being almost universally used. With a self-reading rod, horizontal position and altitude are determined at one operation with surprising accuracy and rapidity, and a command of all points in sight within $\frac{1}{4}$ mile is easily obtained. The limit to the use of the rod is reached when the scale is so far reduced (3 or 4 inches to 1 mile) that the longest range appears as a circle of about 1-inch radius on the map.

Beyond these scales the relative sizes of small objects are lost, and have to be expressed conventionally, while topographical features are generalized, minute details only producing confusion. Whether by method of intersection alone, or combined with linear measurement, the operations are continued until a sufficient number of points have been located to satisfy the requirements of the map, beyond which the map is purely an artistic sketch. The guiding rules are, that no station should be left until all advantageous work has been completed, and that no doubt should exist about the accuracy of locations. Maximum economy is only secured by consulting the requirements of the scale, which limits the amount of detail to be represented, and the precision required in measurements.

The almost universal system adopted in contouring, is to interpolate the position of the curves between points whose differential height is known, instead of levelling and surveying each particular line. The latter system, owing to its cost, is only applicable to comparatively flat country, while the former is universally applied for all scales, and is specially valuable in hilly and mountainous regions.

The United States stands alone in attempting a general topographical survey, and publishing contoured maps of sufficient accuracy for scientific purposes, before the advent of a refined triangulation.

In all other countries topographical surveys have been based on triangulations which have served other purposes, including the measurement of the shape of the earth. There exists, however, in the United States the magnificent triangulation of the Coast Survey, on which much topographical work has been based; although in the interior a more economical system has had of necessity to be studied, and it may be safe to say, it is the result of home, rather

than foreign experience. A favourable climate and atmosphere in the United States has added not a little to the success of the methods pursued. The plane-table has been applied under conditions formerly considered impossible, and much simplified and improved for special work. While plane-tabling forms but one of the many operations of mapping, it will be impossible to do more than give in the latter part of the Paper a few of the successful applications of the instrument.

Owing to widely different conditions in other countries, comparisons of statistics are of little value.

It might, however, be supposed that similar conditions might exist in some of the English colonies, when for example, the cost given per square mile for the New Zealand survey, for a map of 2 miles to 1 inch, including field-work and revision, notes having been taken with 4-inch theodolites, prismatic compass and steel tape, is about nine times as great as the cost per square mile of similar surveys in the United States, where the plane-table has been employed for details. Even with the knowledge of the complex nature of the elements, which modify the cost of field-work, this result is alone sufficient to show the economic value of the instrument.

During the season 1886–87, the United States Geological Survey surveyed and mapped, on the scale of 4 miles, 2 miles, and 1 mile to 1 inch, an area of over 56,000 square miles with a topographical corps of but one hundred and sixty men, at an average cost of about 12*s.* per square mile, the area being greater than England and one-sixth of Scotland. The maps exhibited are characteristic of the results accomplished in the different fields of work, and are typical of almost every variety of physical feature. On many of them it will be observed that the relief could not be expressed without confusion with contours having a less interval than 200 feet.

Other maps show the character of the plane-table work of the U.S. Coast and Geodetic Survey, on the scale of field-work $\frac{1}{10,000}$, where the stadia had been used for contouring and details.

In American practice the preliminary, or field-map, is generally produced on about twice the scale of publication, in order that slight errors in plotting may be practically eliminated when reduced. The extreme limits of reduction from the field-scale to that of publication is illustrated in the case of the topographical land-survey of Wurtemburg, where field-notes were taken with the plane-table on the scale of $\frac{1}{2,500}$, or $25\frac{1}{3}$ inches to 1 mile, and reduced to a scale of 1 : 50,000. One publication sheet represents

four hundred plane-table sheets, reduced twenty times in linear dimensions, the result of such reduction being that between five to eight hundred points are located per square inch, when for comparison on the Prussian and Baden surveys about twenty are considered sufficient.

But little will be found in the literature of the subject regarding the most important application of the plane-table, its immediate value as a secondary triangulation instrument beginning where the geodetic triangulation leaves off, and completing with wonderful accuracy the entire details of a map, not limited to any scale, but with a degree of accuracy limited only by the scale.

The point at which precise triangulation should cease, and graphic triangulation begin, affects not only the economy of the survey, but in a large degree the type of plane-table which can be best used. Opinions differ so widely about the accuracy of the instrument, even for locating details, in the face of important results obtained, that it will be well to examine critically the nature of the sources of error in measuring azimuth angles graphically, by an analysis which would apply to any other type of altazimuth instrument.

Nothing more or less is required on a topographical map than that the errors of geographical position of all located points should be inappreciable. As all depends principally, in plane-tabling, on graphic triangulation, the sole requirement is that errors in measuring azimuth angles should vanish.

An unavoidable source of error, peculiar to the instrument, is the atmospheric or hygrometric effect on the paper or instrument used. The result is that figures are distorted, and exactly the same effect is produced as by inaccurate projection of the triangulation. This is clearly shown on the three-point problem model, when one of the pins or flags is moved from its true position, correct intersection being apparently obtained, with a serious divergence from the meridian; a mechanical demonstration of the problem of projecting one triangle into the form of another. Thus climate limits the value of the plane-table.

II. The Plane-table.

The requirements of construction of a plane-table of precision are the same as those of any other type of altazimuth surveying instrument.

The lower plate of the transit theodolite is expanded, and becomes the plane-table board; the vernier, or index, being

replaced by a straight-edge, which, with the telescope and vertical arc, is commonly called the alidade, or by the Germans the Kipp-regel (Plate 3, Fig. 1). As the alidade alone may weigh several pounds, and is detached, it is essential that the support of the board should be as rigid as possible.

The Edgeworth stadiometer is, however, a type of plane-table, having an attached alidade, each sheet being but the record of the work done at one station (Plate 3, Fig. 2).

In plane-tables of the common type, the first requirements are that the upper surface of the table should be plane or true, supported rigidly in a horizontal plane, and have a vertical axis of revolution, about which the table can be turned for adjustment to the meridian, without disturbing either its rigidity or level. How far these requirements are carried out in practice may be judged by a comparison of the principal types in common use; the most difficult of these conditions to fulfil being that of obtaining a horizontal plane on which to work.

In general, to save weight, wooden boards are used varying greatly in size, from a square of 14 inches or less, to a rectangle of 24 inches by 30 inches, which appears to be practically the limit. Probably every wood has been tried, without successfully obtaining a material which will not warp under great changes of temperature or moisture. Tables have been constructed of brass, and, in Germany, even of heavy plate-glass. The German instruments appear to be unduly heavy, weighing from 18 to 25 kilograms (40 to nearly 60 lbs.), or twice as heavy as the American instruments designed for the same class of work. This can be explained by comparing the details of construction.

The plane-table consists of three parts:—1. The board; 2. The movement; 3. The tripod. The best form of tripod is the common split, or double-leg, tripod, with a wide head.

In the modern types the table is generally supported on three levelling-screws rising from the tripod head, and, after adjustment to a horizontal plane, is rigidly secured by some form of clamp which does not disturb its position. The vertical axis of rotation is secured in a variety of ways. In general, any surface of revolution is suitable, but the more common types are the cone, the sphere, and the annular ring, alone or combined.

In addition to the theoretical requirements, stability and portability have to be considered. The short cone suitable for a theodolite is quite unfitted to carry the greater weight of the plane-table board and shifting alidade.

In the instrument of the Prussian Land Survey (Plate 3,

Fig. 3), it will be seen that the cone has been greatly lengthened, and, in addition, a small spherical or annular surface of support is provided. The diagram gives but a section of a small portion of the movement to show the construction of the axis. Complete, the weight of the instrument, including tripod, movement, and board, is about 50 lbs. A recent modification, by G. Heyde, of Dresden (Plate 3, Fig. 4), deserves notice, as it weighs about 15 lbs. less, and might be made still lighter with modified tripod. The section shows a short conical axis, and in combination with it a wide annular surface of support. Maximum stability and lightness are secured in the United States Coast Survey type (Plate 3, Fig. 5), where the cone has practically disappeared, and is replaced by a short cylindrical axis for centering; stability being obtained by support on a wide V-shaped annular surface; the instrument rarely exceeding 20 lbs. in weight. The whole construction of the late plane-table of the Coast Survey deserves special attention, particularly the details of the alidade, or sighting-ruler, as it is based on the continuous experience of fifty years' service.

Of the sphere, the most obvious type is the ball-and-socket. This was originally designed to secure an axis of rotation in any plane, and hence is least adapted to secure stability in a horizontal one. Numerous modifications of the ball-and-socket are found, a history of which would be most voluminous. Among others, it is of interest to examine those which have special reference to the plane-table.

Early in this century the French modified this type of levelling movement in an original way. The "genou de Cuynot" (Plate 3, Fig. 6), with two axes of revolution at right-angles to each other, and independent clamps, was a marked improvement, but not stable, the centre of gravity being high above the axes of support.

The Germans have contributed most numerous and ingenious modifications in applying levelling screws to the ball-and-socket.

As the plane-table can always be set up approximately level by the legs of the tripod alone, however rough the ground, only a small angle for adjustment is needed—10° at most. Hence the happy modification of hollowing out the sphere and clamping it on the convex and concave surfaces. In this way great stability can be secured by using a bowl-shaped section of a sphere of 8 or more inches in diameter. An American instrument of this type, designed by Gurley Bros., of Troy, New York, is shown in section (Plate 3, Fig. 7). The extreme simplicity and rigidity of this type of ball-and-socket led to a recent improvement, by Mr.

Willard D. Johnson, of the United States Geological Survey (Plate 3, Fig. 8), which was at once accepted for mountain service on the Geological Survey, and for various instruments on the United States Signal Service. It is probably the most rigid, efficient, and portable type of plane-table movement yet devised. The extreme rigidity, obtained by the slightest pressure on the thumb-screws, arises from the friction of the large areas of spherical surfaces in contact, which should from their form improve by wear.

A recent French military instrument (Planchette à calotte sphérique) (Plate 3, Figs. 9 and 10), or plane-table with spherical cap, properly belongs to the same class, the chief difference in construction being that the spherical surface is reversed. The two clamping screws are below the tripod-head as before, at or near the centre of the sphere, the convex surface of which is alone utilized in clamping the levelling axis. In addition to the levelling and azimuth adjustments, provision is made in a simple manner for an adjustment of the parallax or eccentricity of the station, the construction of which will be seen from the diagram.

The theoretical requirements in setting the plane-table over a station are: 1. That the plane of the board should be horizontal. 2. That the station on the map should be vertically over the point represented on the ground. 3. That the meridian of the point on the plane-table sheet should be in the plane of the meridian of the station.

Of these requirements, the first is met by proper construction, the third by adjustment in azimuth. In setting the plane-table up, the error of eccentricity cannot be determined until the board has been levelled and adjusted in azimuth. At first sight it would appear that such an error could not be neglected, and that a mechanical adjustment would be a convenience. Numerous mechanical contrivances have been designed to meet this adjustment; among them the French instrument (Plate 3, Figs. 9 and 10) just described, and the slide-rest motion of Bauernfeind (Plate 3, Fig. 11) lend only additional weight and source of error, without having any practical value.

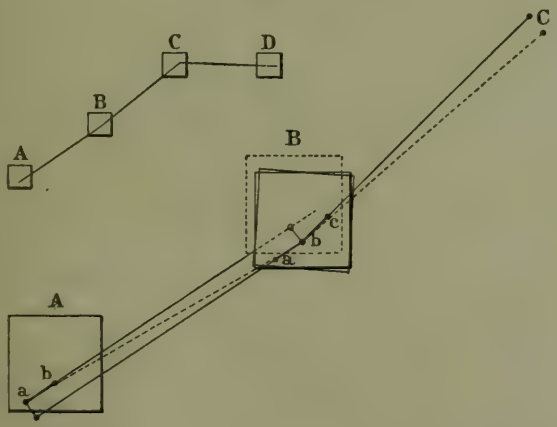
The difficulty of meeting the three theoretical requirements in practice has led a number of recent writers to assume that the plane-table is a clumsy and inaccurate instrument. For illustration, the plane-table can readily be set up, levelled and adjusted in azimuth within 6 inches of its true position, without the aid of a plumb-line. At the range of $\frac{1}{2}$ mile such an error would subtend an angle of less than 1′, at $\frac{1}{4}$ mile only about $1\frac{1}{2}$′, angular errors

which may be neglected within the limits of the plane-table sheet. As the distance is diminished the angular error would naturally become greater, but remain inappreciable.

Serious accumulative errors occur in traversing when such a source of error is neglected. They may, however, be reduced to a minimum in a simple manner.

In traversing the line A B C, &c. (Fig. 3), the plane-table is set up and adjusted at A, and the line *a b* drawn through *a* towards B. The distance and height of B are obtained with a self-reading rod graduated in convenient units for the telescope used. Before leaving A its true position is found on the ground and marked, either by the use of a plumb-line, or, for all practical purposes equally well, by dropping a pebble from

FIG. 3.



a point below the station on the board. However short or long the line *a b* may be, "repere," or reference marks are drawn at the extreme ends of the rule.

At B the board is adjusted in azimuth by the line *b a*, the telescope having been reversed in direction, and the ruler adjusted by the "repere" marks. An error of a few inches in eccentricity at B would, if neglected, be communicated to all the following lines of the traverse.

Instead of attempting a rigid adjustment of the plane-table, it is far more simple to produce a similar error at A, and, eliminating angular error, the result is solely confined to an error of geographical position, inappreciable on any common scale. In

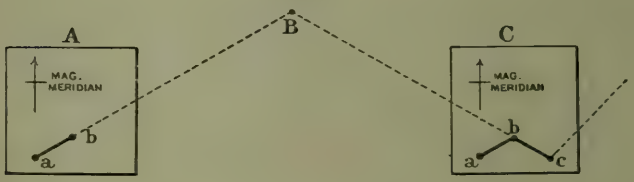
addition, the line A B may be again measured and checked telemetrically in length and inclination.

Theoretically, the absolute height of the instrument above the ground should be measured. Practically, it is more convenient to assume an average height, which will be about 4½ feet, and have a standard mark on the rod, used for back-sights and for fore-sights.

The lines B C, C D, &c., are measured in the same way, and in this manner, using simple precautions, it is quite possible to run traverses for several miles, without appreciable graphic errors or serious errors in altitude. The traverse may, however, be run in a more rapid manner by setting up at alternate stations, A, C, &c., adjusting the board by magnetic needle (Fig. 4). In this case no check is afforded for the linear measurement of the links, but the angular errors are confined to local variations of the compass, and the differential heights of the turning-points B D, &c., are obtained independently of the variable height of the instrument.

It can be established beyond dispute that, in point of economy in field- and office-work, no other system of mapping can compete

FIG. 4.



with plane-tabling under favourable conditions. In point of accuracy, it remains to be seen whether a map constructed in the field geometrically can compete with one carefully checked by tables of trigonometrical functions.

Since none but a graphic record is kept of the angles measured on the plane-table, it is necessary to consider the nature of the sources of error in measuring azimuth angles. If it can be shown from the construction of the instrument that these may be neglected, then for all practical purposes the plane-table may be ranked as an instrument of precision.

The Alidade.

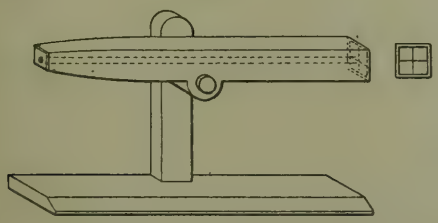
The most simple and ancient type of alidade, or rule, is a flat, straight-edge, with raised sights (Fig. 5). The plane of the sights should be at right-angles to the plane of the ruler. It is immaterial whether it coincides with, is parallel to, or even inclined to the fiducial edge of the rule against which the pencil is traced. The two edges of the rule being parallel, either can

Fig. 5.

be used at will. If the sights were centered on a ruler 2 inches wide, the angular error produced at 100 feet would amount to less than 3′. If inclined to the fiducial edge, the actual angles observed would be recorded correctly if the error remained constant.

When the raised sights are replaced by a telescope (Fig. 6), the requirements of construction, to secure accuracy in the mea-

Fig. 6.



surement of azimuth angles, are, that the line of sight or collimation of the telescope should move in a vertical plane when the rule is horizontal, or, obviously, that the transverse axis of rotation of the telescope should be at right-angles to the line of collimation and parallel to the plane of the ruler.

Three sources of instrumental error are suggested—

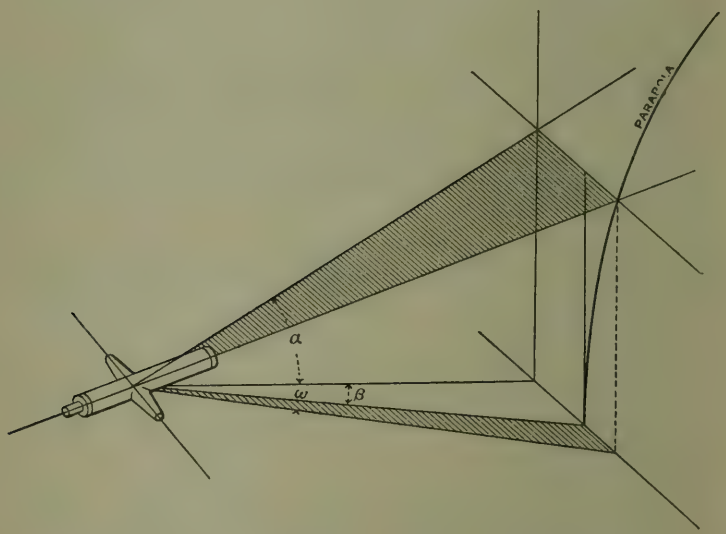
1. An error of collimation.
2. An inclination of the transverse axis.
3. The board, or the plane of the ruler, being out of level.

An error of collimation arises when the line of sight is not at

right-angles to the transverse axis (Fig. 7). This may come from faulty construction, or more commonly from a displacement of the diaphragm holding the cross-hairs. The nature of the error produced is clearly shown in the accompanying model.

In any other position than at right-angles to the axis of rotation, the line of sight becomes the element of a cone, and a conical surface is developed instead of the required vertical plane. If the telescope is directed to a vertical plumb-line, the intersection of the cross-hairs being passed up and down, it will be observed that the index, corresponding to the vernier of the theodolite will be deflected from the position first sighted above the horizon, and

Fig. 7.

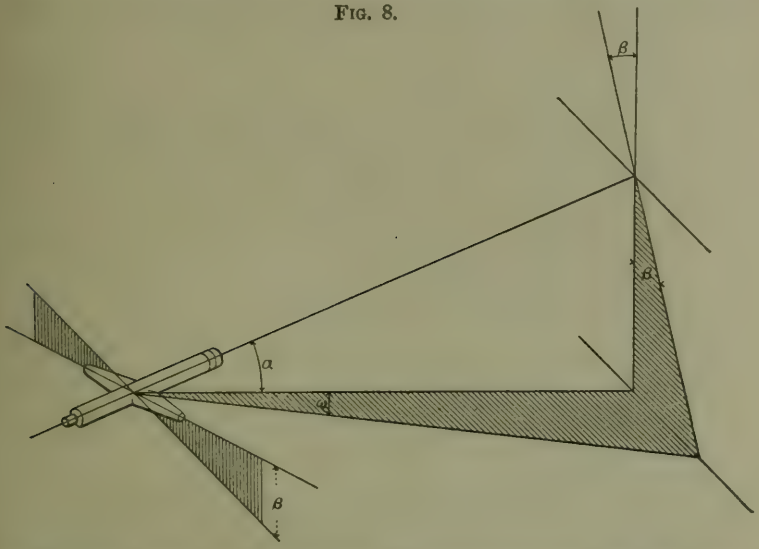


return to the same point when a similar point has been reached below. Or, if the index is firmly held in one position, the cross will apparently describe a parabola in the field of the telescope. If the transverse axis alone is inclined, the line of sight will describe a plane not vertical (Fig. 8) and, in consequence, if the telescope is directed to the plumb-line, the index will be deflected in one or other direction according as the telescope is moved up or down.

The most common source of error in plane-tabling arises from the shifting centre of gravity of the upper part and unsteadiness of the movement, resulting in the error of board out of level.

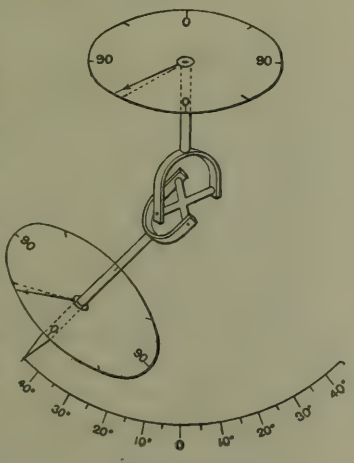
For convenience in analysis, let it be assumed that the instrument is otherwise in perfect adjustment, that is, that the line of

FIG. 8.



collimation is at right-angles to the transverse axis, and the latter parallel to the plane of the index. The telescope being revolved in a horizontal plane, the transverse axis will, from construction, revolve in a plane parallel to the index or table. In consequence, if the telescope revolves in its plane at a uniform rate, a periodic motion is conveyed to the index, which will only be in correct position at four points, between which the rate of revolution is very variable. The action is precisely similar to that of a Hooke's joint, a very clear demonstration of which is given in a recent work by Professor A. B. W. Kennedy[1] (Fig. 9). In one direction a horizontal line may be drawn on the inclined board. Calling the two ends of this line zero, and

FIG. 9.

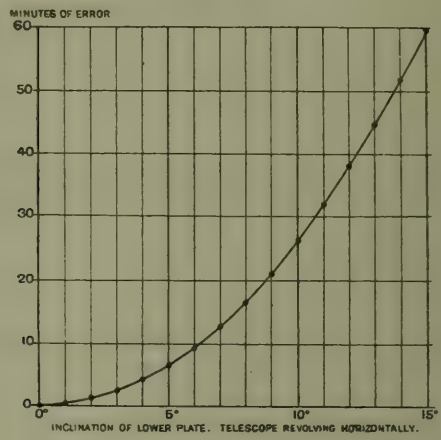


[1] The Mechanics of Machinery. 1886. p. 498.

the ends of a line at right-angles 90°, the index and telescope will point in the same direction at these four points. Starting from zero, or 90°, the maximum error occurs when the sum of the angles turned by the index and telescope is equal to 90°, or the mean angle is 45°.

The accompanying Table and curve (Fig. 10), show the value of the maximum error for different inclinations of the board from a horizontal plane. The model shows more clearly the nature of the error.

FIG. 10.



By calculation, an error of board out of level of 1°, produces a maximum azimuth error of but 15″, which would be barely appreciable at about 12 feet. An error of 3°, produces one of about $2\frac{1}{3}'$, appreciable at 18 inches, an error which may be neglected in ordinary mapping within the limits of the plane-table sheet. If 10° out of level, the maximum error is less than 30′, if 15° less than 1°.

These results show that in flat country slight errors of level produce inappreciable errors in azimuth angles, and account for the remarkable results obtained in India with rough plane-tables. Such a source of error cannot be neglected in mountainous or hilly country, when altitude-angles commonly exceed 10°, and sometimes amount to 30°, or more, at short range. The board out of level then produces an inclination of the plane of the sights, or tilt of the transverse axis.

Assuming other adjustments to be perfect, an error of 1° inclination of the transverse axis produces an increasing error of about 1′ in azimuth for each degree of vertical angle. For 1° out of level,

at 30° elevation or depression, the azimuth error would amount to about 30′. Obviously to secure perfect results in graphic triangulation, azimuth errors should not exceed 2′. This degree of precision is only met by proper construction of the alidade and plane-table.

An error of collimation produces but one-tenth the effect of a similar error in the transverse axis.

The construction of the alidade employed for accurate work deserves attention, particularly the simplicity of the one designed by Professor Hilgard, late Superintendent of the United States Coast and Geodetic Survey. The plane-table was adopted by the Coast Survey early in the century, owing to the success of the well-known Swiss contoured maps. It is of value to note that the Prussian instruments of to-day show details of construction long since rejected in the American instrument.

The telescope of the Prussian Land Survey Kippregel (Plate 3, Fig. 12) is supported on a conical transverse axis. This introduces a possible source of error from wear, which would produce an inclination of the transverse axis to the plane of the rule. To meet this, adjusting-screws are placed at the foot of the column. It is well known that all screws have a tendency to become loose, and are frequently lost in transportation. To introduce such a source of error and its adjustment is unnecessary.

In the American alidade (Plate 3, Fig. 13) this adjustment is left to the maker. The telescope is supported on Y's at the top of a solid column, which serves as a convenient handle. The instrument exhibited is a slight modification of the Coast Survey pattern, much smaller, and constructed for mountain service, but it shows the special features of construction to be noticed. The telescope is supported near its centre of gravity in a collar, in which it can be revolved 180°, stops being fitted for that range. This admits of an easy adjustment of the cross-hairs, and, in addition, with a striding-level and vertical arc, a means of obtaining vertical angles free from errors of level, collimation, and revolution. The latter error arises when any eccentricity exists in the two cylindrical surfaces which support the striding-level.

An old pattern of German Kippregel is shown in section (Plate 3, Fig. 14). For the adjustment of collimation, the telescope was constructed to transit on its Y's through the column of support.

By way of novelty the American alidade exhibited has a larger arc than is commonly provided, and carries a solar attachment, to obtain without calculation an astronomical meridian from a simple solar observation. Astronomers would say that a telescope only

3 inches in length was unfitted for such work; but the solar attachment has been widely used in the United States for fifty years, for running meridian lines in places where the magnetic needle was out of the question, with a degree of precision far exceeding the compass, and sufficient for mapping purposes.

A recent French military alidade for stadia work is exceedingly compact, and would probably be a valuable addition to the outfit of the engineer. The construction will be seen from Plate 3, Fig. 15. In place of cross-hairs, fine lines are photographed on one of the faces of the prism.

It has been impossible to enter minutely into the details of construction, the adjustments, or manipulation of the instruments exhibited.

Recent results and improvements show, beyond a doubt, that a far greater degree of precision can be obtained from simple graphic triangulation than is commonly supposed, amply sufficient for purposes of mapping, and with a degree of economy unequalled by other systems. The colonial engineer, or student, cannot afford to lose sight of a valuable and simple instrument, with which he can, even alone and unassisted, construct a topographical map of any scale, with a degree of precision only limited by the scale, and in the same time that he would occupy in taking observations with other instruments.

III. Plane-tabling.

Plane-tabling is, briefly, the construction of a map on the geometrical laws of similar figures.

The instrument being properly constructed, errors of level, collimation, and transverse axis need not exceed a few minutes. A close analysis shows that if such is the case the resulting errors in azimuth will be so minute that they may be neglected. Thus, any two points being taken on the sheet as a base, a map may be constructed independent of scale, yet perfect in its proportions by method of intersection alone.

When the elements of trigonometrical surveying are observed, the extension from a long base on the plane-table sheet is a contracting one, with diminishing chance of error; and each pair of intersections, which have been tested geometrically, becomes, in turn, a base for minor triangulation. On such a system the remarkable survey of Lake Mono (kindly communicated by Mr. Willard D. Johnson) was accomplished. Apart from its geographical interest, it contains many suggestions of value.

The method of locating soundings over a wide area, by operating two plane-tables in concert, at equal time intervals, is novel, although successfully applied in many ways.

The same system has been tried with great success, over areas of open country, where the method of intersections was impossible, in mapping a net-work of ravines. A suitable base having been chosen, simultaneous observations were taken on a flag carried by a man in the saddle, who galloped rapidly over the area, stopping at suitable points for location, the notes of one sheet being finally transferred to the other. In this way an area of many square miles was surveyed in a most rapid manner, with details which otherwise could only have been obtained by long and tedious traverse lines. Among the diagrams exhibited will be seen a series of rough profile, or panoramic sketches, traced from the field note-books of a survey of the head-waters of the Missouri. On the American Geographical Survey of large areas, a continuous series of such sketches is taken from each station occupied with a theodolite, and above each point sighted is placed a record of the observed angles. Such sketches, however rough, are of great value in the final construction of the office map, not only as a record of observations, but of form.

The plane-tabler has daily before him the panorama of nature, from which in a far more perfect manner hill-features are sketched boldly, and submitted to constant criticism and correction. Where many natural objects are sighted, the profile sketch is a most convenient form of record, and does away with written descriptions and cases of mistaken identity. In addition, on geographical surveys, the drainage sketches from commanding points are most important. The natural tendency is to foreshorten everything viewed in perspective, particularly the courses of streams at a distance.

On working up the notes of such a survey the operations are:—

1st. The adjustment and plotting of the triangulation, on the desired scale.

2nd. The projection of the drainage.

3rd. The adjustment of the trigonometrical and barometrical levelling.

Finally, The interpolation of continuous contours guided by the sketches taken.

On the recent surveys of the Yellowstone Park, it was found most convenient to construct continuous drainage sketches on light plane-tables, in addition to observations taken with other

instruments. These plane-tables had rolling boards, light folding tripods and ruler with raised sights, similar in type to the military reconnaissance instrument, being constructed for easy transportation in the saddle. The resulting sketch was in reality a reconnaissance of the whole area surveyed, and far better to work from than the customary sketches of the note-book.

In the case of maps constructed on the basis of secondary triangulations, the first operation in field-work is to erect signals on the established points; these being, in many cases, only marked by a copper bolt in a ledge, are often in the course of a few years covered with moss or brush, and difficult to find. The following instance, given by Mr. Alex. W. Longfellow, of the Coast Survey, illustrates the utility and accuracy of a location by the three-point problem. After searching in vain for a bolt on a commanding point, the plane-table was set up and the position found by the three-point problem. The instrument then indicated the desired direction and distance with the slightest error, due to the scale (1 : 10,000) of map, of about 3 feet.

Attention has chiefly been directed to the value of the plane-table as an altazimuth instrument. The construction of the Hilgard alidade is such, that, with the double observation referred to, altitude angles can be measured to the nearest minute free from instrumental errors. The stadia-hairs in the diaphragm furnish a ready means of determining height and distance by a single observation on a graduated vertical rod, with a degree of accuracy sufficient for topographic work, and in positions where chain and level are out of the question. Recent developments in Germany have given the rod a range of 1,200 metres, or nearly $\frac{3}{4}$ mile. The precision in horizontal measurement at short range is well known to be equal, if not superior, to chain-measurements. At long range, the thickness of the cross-hairs hides the minute divisions seen in the image.

In connection with the level, the plane-table is commonly used in the United States for special work in constructing maps of large scale and great detail, showing surface contours of 1 foot or 2 feet vertical intervals for the use of the landscape gardener, or plans for estimating excavation.

No country in the world is better provided than England with triangulation and reliable bench-marks, established by the admirable Ordnance Survey, on which minor plane-table maps could be based. While, on the other hand, no climate is less favourable for an extended survey with the instrument. It having, within a very short period, been introduced almost as a novelty in military

circles, after years of rest, it is possible that it may again find a place in the outfit of the engineer.

In conclusion, the Author desires to acknowledge the many kind suggestions, during the preparation of the Paper, received from Lieut.-Colonel T. Hungerford Holdich, R.E., Professor Henry Robinson, M. Inst. C.E., Professor A. G. Greenhill, Mr. Willard D. Johnson, and others.

The Paper is accompanied by numerous illustrations, from which Plate 3 and the Figs. in the text have been engraved.

APPENDIX.

For information about the methods used in American geographical surveying, *vide*—

1. Professional Papers of the Engineer Department U.S. Army, No. 18. Report of the Geological Exploration of the Fortieth Parallel, &c., by Clarence King, 1878. Vol. i. p. 762, Appendix, by James T. Gardner. Geodetical and topographical methods used.

2. U.S. Geographical Surveys West of the 100th Meridian. Wheeler, 1883; p. 47, Primary Triangulation; p. 500, part ii., Results in Barometric Hypsometry obtained during the years 1871 to 1875, by 1st Lieut. Wm. L. Marshall.

3. Appendix VI, Report 1883, United States Coast and Geodetic Survey, contains a general index of scientific papers.

4. An article by Mr. Henry Gannett in "Science," July 29, 1887, on the "Topographical Survey of the United States," describes the work of the U.S. Geological Survey, and treats in a novel manner the problems of cost and precision, &c.

5. The statistics of rate of progress, etc., have been largely drawn from the above, and the Report upon the Third International Geographical Congress and Exhibition at Venice, Italy, 1881. Captain Geo. M. Wheeler, Washington, 1885.

The extent of the triangulation on which detail is based is, in general, expressed by the number of points scattered over a given area, or of the number required for the plane-table sheet. In India seventy or eighty such points are projected on the plane-table sheet, and the instrument is chiefly used for filling in detail. In Prussia at least thirty were insisted upon by the Central Commission, held May 11, 1872, instead of two or three formerly considered sufficient. The United States Coast and Geodetic Survey establish secondary and tertiary stations about 1 or 2 miles apart for the use of the plane-tabler. Recent results with the improved instruments used on the U.S. Geological Survey, have proved that a multiplication of points is a detriment rather than an advantage; precedence being given to those established graphically. For greater simplicity these results are reduced to their average distance apart in miles, and inches apart on paper, by the following approximate formula, an application of that used in calculating the number of wires of given diameter d in a rope of given sectional area

$$n = \text{area} \times \frac{2}{d^2\sqrt{3}}, \qquad \therefore \qquad d^2 = \frac{\text{area}}{n} \times \sec 30°.$$

The same result may be obtained independently by taking a series of belts of equilateral triangles enclosed in a rectangular area.

——	Points on which to base detail.	Area.	Inches apart, Field Scale.	Miles apart.
Prussia	32 to 34	2½ German square miles . . .	3⅓ inches	1·32
Belgium	43	640 square kilos.	..	2½
Bavaria	50 to 60	Per German square mile	1·8 inch 1·6 „	0·711 0·640

1 square kilometre = 2·48 square inches. Scale 1:25,000.
1 German square mile = 21·907 statute miles.

In Bavaria, bench-marks vary from six in the south-eastern part to sixty in the Palatinate, to the German square mile—

$$= 1{\cdot}96 \text{ to } 0{\cdot}62 \text{ mile apart.}$$
$$= 4{\cdot}9 \text{ „ } 1{\cdot}55 \text{ inch apart.}$$

and eight hundred to one thousand altitudes are determined in the same area—

$$= 5{\cdot}85 \text{ to } 7{\cdot}1 \text{ per square inch.}$$

In Prussia and Bavaria maps are reproduced on the same scale as the plane-table sheet 1 : 25,000 (about $2\frac{1}{2}$ inches to 1 mile).

The advantages of working on the smaller scale, greater economy and rapidity, are in a large degree lost by the greater tax on the draughtsman. To illustrate this, the *Prussian plane-tabler*, working on the 1 : 25,000 scale, using stadia for details and contours, is able to accomplish from $\frac{1}{3}$ to $\frac{1}{2}$ square mile per day. The utmost limit at which this rod can be read is 600 metres, represented by a circle of radius less than 1 inch on the map.

The *Italian plane-tabler*, working on the scale 1 : 20,000, accomplishes about $\frac{1}{3}$ square mile per day. Yet the *American coast-surveyor*, on the 1 : 10,000 scale, using practically the same instrument and methods, accomplishes fully as much ($\frac{1}{4}$ to $\frac{1}{2}$ square mile per day) with most elaborate detail, all that can be accomplished on the scale, or an area of his sheet fully seven times as great.

The *Austrian topographer*, with two or more soldiers, is able to accomplish about 1 square mile per day on the scale of 1 : 25,000, the published maps being almost exact reproductions of the plane-table sheets reduced one-third, or to a scale of 1 : 75,000.

Plane-table contouring (rate with stadia).—The Bavarian topographer starts out with a sheet of the cadastral map on which is given a number of accurately levelled bench marks about $\frac{3}{4}$ of a mile apart. By trigonometrical levelling and aneroid readings in pairs, about six or seven altitudes per square inch are determined, and between these points 5 or 10 metre contours are interpolated and corrected in the field. At the end of a month between 14 and 15 square miles are ready for revision and publication.

Wheeler[1] also mentions, p. 457, that for the general preliminary map of the empire of Japan on scale 1 : 800,000, the topographers are provided with small plane-tables and travellers' theodolites, perambulators for distances, and magnetic needles. Each plane-table sheet $= \frac{1}{12}$ of a half-degree and is made on the scale of 1 : 50,000. One group, topographer and two geologists, complete $\frac{1}{6}$th degree in four months, an area of about 625 square miles, at a rate of $4\frac{3}{4}$ square miles per day, or four plane-table sheets in the season.

The greater rate on smaller scales on the United States Geological Survey topographical surveys (*vide* Reports) arises from the large number of natural objects sighted and located, by method of intersection, it being impossible, owing to the scales used, to record minute measurements.

Topographical surveying being untrammelled with the measurements of property boundaries and areas, maximum economy is only secured by taking a unit of linear measurement adapted to the scale. Thus, on the United States Coast and Geodetic Survey the unit chosen as most convenient is the metre, while 10 feet would give sufficiently accurate results. The metre is perhaps safer for traversing, and gives a closer approximation in vertical measurements. The latter is, however, expressed in feet, the scales of mapping being 1 : 20,000 and 1 : 10,000, or greater.

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[1] Report upon the Third International Geographical Congress and Exhibition at Venice, Italy, 1881. Captain Geo. M. Wheeler, Washington, 1885.

The false estimation in reading measurements with the stadia-rod of a few units produces slight errors in height, which in general can be safely neglected. The formula on which stadia measurement is based, with a horizontal sight, is in the form

$$d = k \,.\, a + c \text{ approximately,}$$

d = distance, k variable, a = space intercepted on the rod by the wires, and c a constant. On slope measurements this is reduced in terms of angle. The constant c is also affected, but, for greater simplicity in plane-tabling, is neglected as too minute to be expressed on the scale, and for greater convenience the rod is arbitrarily graduated in equal units, established by experiment on a measured base.

In the measurements of heights, at distances beyond the limits of the rod, a scale measurement from the map is considered sufficiently accurate for horizontal distance.

If h = required height.
α = observed angle.
d = measured distance.

$$\pm h = \pm d \tan \alpha,$$

or, on observing a signal of height l, (i) being the height of the instrument—

$$\pm h = \pm d \tan \alpha - l + i.$$

In observing a series of altitudes from one spot, it is of value as a check on trigonometrical levelling to keep a table for reference of the differential heights of established points. Thus, if the difference in heights above sea-level of A and B is known to be x, $h_A - h_B$ should $= x$ from all points.

Probably the best existing treatise on the modern plane-table is that of Mr. E. Hergesheimer, U.S. Coast Survey Report of 1880, Appendix 13.

Unfortunately no treatise exists of the recent use of the plane-table in geographical surveying. Hergesheimer gives, as a convenient formula for determining heights by vertical angles, the following, which will have to be used with caution, except at low angles:—

$$h = \tfrac{1}{1,000} d \times (\alpha \text{ in minutes}) - \tfrac{1}{20} \text{th.}$$

where h = required height.
d = measured distance.
α = angle in minutes.

This formula is based on the assumption that α varies as tan x (true for small angles), and has an additional source of error in the constant arising from a false value being taken for the metre expressed in feet. It, however, gives exceeding close results at small angles of elevation or depression.

At 1,000 metres let n be derived from the formula $h = \tan \alpha$, and h' by the above.

At 1°	h = 57·27	feet,	h' = 57	error 0·27	feet.
2°	,, = 114·57	,,	,, = 114	,, 0·57	,,
3°	,, = 171·94	,,	,, = 171	,, 0·94	,,
4°	,, = 229·42	,,	,, = 228	,, 1·42	,,
5°	,, = 287·04	,,	,, = 285	,, 2·04	,,
6°	,, = 344·84	,,	,, = 342	,, 2·84	,,
7°	,, = 402·84	,,	,, = 399	,, 3·84	,,
8°	,, = 461·10	,,	,, = 456	,, 5·10	,,
9°	,, = 519·64	,,	,, = 513	,, 6·64	,,
10°	,, = 578·50	,,	,, = 570	,, 8·50	

The special feature of the Hilgard alidade which deserves attention is the perfect construction adopted to facilitate the measurement of altitude angles, free from instrumental errors, with a small arc.

From Hergesheimer's treatise, p. 4: "The telescope is fitted accurately near its centre of gravity within a closely-fitting cylinder, to which is solidly attached the transverse axis. The telescope revolves within this cylinder 180°, stops being fitted for that range. This affords an easy mode of adjusting the cross-webs to the axis of revolution, and for correction with a striding-level, of the errors of level and collimation and of revolution of the telescope. Upon the tube of the telescope are turned two shoulders on which rests a striding-level, which can readily be reversed or removed at pleasure."

It should be observed that a striding-level can be adjusted on any surface of revolution, cone or cylinder, &c.; hence the requirements of construction are that the two cylindrical shoulders, which support the level, should be of equal diameter, and have coinciding axes. Any eccentricity of the bearings will be indicated by a varying index-error when the level is in adjustment. The following may serve as an example, Hergesheimer, p. 22 :—

TELESCOPE DIRECT.

Level direct, reading	+0° 1′	
Level reversed ,, ...	0′	
Mean	+0° 0′·5	
Station, reading.	+2° 17′	
Elevation (difference)		2° 16′·5

TELESCOPE INVERTED.

Level direct, reading	−0° 2′	
Level reversed ,, ...	− 1′	
Mean	−0° 1′·5	
Station, reading	+2° 12′	
Elevation (difference)		2° 13′·5
Mean		2° 15′

It will be seen from analysing this observation that the level was 30″ out of adjustment, the horizontal wire 30″, and that revolving the telescope about itself changed its relation to the index on the vernier by 1′. The mean is free from all errors of adjustment.

SOURCES of ERROR in MEASURING AZIMUTH ANGLES with a THEODOLITE, or PLANE-TABLE, out of ADJUSTMENT.

The requirement is that the angle measured should be the horizontal projection of the observed natural observed angle; and, for construction, that the telescope should move in a vertical plane when the plane of the index is horizontal.

The results given are arrived at in the following manner:—An error of collimation arises when the line of collimation is not at right-angles to the transverse axis on which the telescope is supported. Assuming other adjustments perfect, the line of collimation will describe the surface of a cone, instead of the required vertical plane, as shown by the model. Should the error remain constant, and the telescope revolve solely in a horizontal plane, the index would record correctly the amount of revolution. When the transverse axis is not horizontal, other adjustments being perfect, the telescope will describe a plane not vertical (Fig. 7).

Error of collimation—

Let β = error $(90° - \beta)$ = inclination of element of cone to axis.
α = observed vertical angle.
$\tan \omega = \tan \beta$ at 0°.

$$\text{Then} \qquad \tan \omega = \frac{\tan \beta}{\cos \alpha}.$$

The variable error in azimuth produced by the constant error of collimation is expressed by $(\omega - \beta)$.

In the following Table α is taken constant at 10°, and $(\omega - \beta)$ calculated for values of β from 1° to 10°.

$\alpha = 10°$

1°	collimation error	0′ 55″	azimuth error = $\omega - \beta$.	
2°	,, ,,	1′ 51″	,,	,,
3°	,, ,,	2′ 46″	,,	,,
4°	,, ,,	3′ 41″	,,	,,
5°	,, ,,	4′ 36″	,,	,,
6°	,, ,,	5′ 31″	,,	,,
7°	,, ,,	6′ 25″	,,	,,
8°	,, ,,	7′ 18″	,,	,,
9°	,, ,,	8′ 11″	,,	,,
10°	,, ,,	9′ 04″	,,	,,

Error transverse axis (Fig. 8)—

α = observed vertical angle.
β = inclination of transverse axis.
ω = error in azimuth.

$$\text{Then} \qquad \tan \omega = \tan \alpha \tan \beta.$$

Let $\alpha = 10°$. $\beta = 1°, 2°, 3° \ldots$ to 10°.

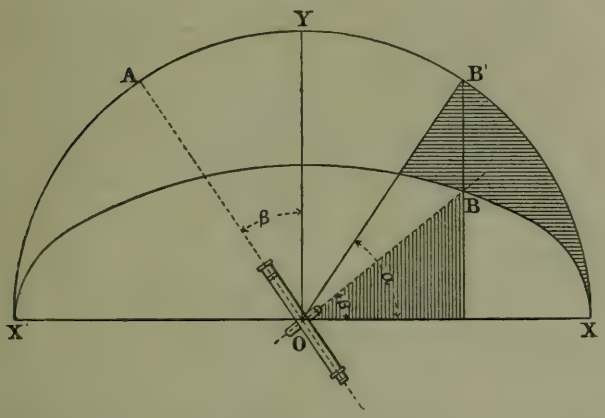
$\beta = 1°$	ω	0° 10′ 35″
2°	,,	0° 21′ 10″
3°	,,	0° 31 46″
4°	,,	0° 42′ 36″
5°	,,	0° 53′ 01″
6°	,,	1° 03′ 42″
7°	,,	1° 14′ 25″
8°	,,	1° 25′ 10″
9°	,,	1° 35′ 59″
10°	,,	1° 46′ 51″

If the theodolite is out of level, or the board, in the case of plane-table,

required the maximum error when the telescope moves in a horizontal plane, and the other adjustments are perfect (Fig. 11).

Regarding the problem as a case of the universal, or Hooke's joint, it admits of easy solution. The arms of the centre link are represented by the telescope and transverse axis respectively, and projected on the horizontal plane in which the telescope moves will always appear at right-angles to one another.

FIG. 11.



Let α be the observed angle measured by the index, or that turned by the transverse axis from its horizontal position.

β the angle turned by the telescope in the horizontal plane.

θ the inclination of the board or error of level.

Then $$\frac{\tan \alpha}{\tan \beta} = \frac{a}{b} = \frac{1}{\cos \theta} = \text{a constant} \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where a and b are the axes of the projected ellipse.

By expansion $(\alpha - \beta) =$ a maximum, when $(\alpha + \beta) = 90°$

and $(\alpha - \beta) =$ a minimum, when $\alpha = \beta = 0°$ or $90°$

Also, when $(\alpha - \beta) =$ a maximum—

$$\sin \alpha = \cos \beta = \sqrt{\frac{a}{a+b}} = \sqrt{\frac{1}{1+\cos \theta}} \quad . \quad . \quad (2)$$

and $$\cos \alpha = \sin \beta = \sqrt{\frac{b}{a+b}} = \sqrt{\frac{\cos \theta}{1+\cos \theta}} \quad . \quad . \quad (3)$$

From equations (1) and (2) the accompanying Table has been calculated, giving the maximum values of $(\alpha - \beta)$, for values of θ from 1° to 15°; or, in other words, the maximum errors in azimuth, in measuring horizontal angles, with a theodolite or plane-table out of level—

θ.	α			β.			Maximum Errors.	
°	°	′	″	°	′	″	′	″
1	45	00	08	44	59	52	0	16
2	45	00	36	44	59	53	1	03
3	45	01	10	44	58	49	2	21
4	45	02	06	44	57	54	4	12
5	45	03	16	44	56	43	6	33
6	45	04	43	44	55	16	9	27
7	45	06	26	44	53	34	12	52
8	45	08	24	44	51	33	16	51
9	45	10	38	44	49	20	21	18
10	45	13	09	44	46	50	26	19
11	45	15	57	44	44	03	31	54
12	45	18	59	44	41	01	37	58
13	45	22	12	44	37	42	44	36
14	45	25	55	44	34	05	51	50
15	45	29	47	44	30	14	59	33

From the above it appears that a theodolite may be 15° out of level before the maximum error in the measurement of a horizontal angle will approach 1°.

Also the error in azimuth angle is a maximum when $\alpha + \beta = 90°$.

The above results may be obtained with the following simple formula: θ = error of level in minutes, l = maximum error in seconds.

Then $$l = \frac{\theta^2}{230} \text{ approximately} = \frac{\theta^2}{229} \text{ very nearly.}$$

It may be observed that to secure most accurate results with the tangent galvanometer, in measuring a resistance, the deflection is taken as near 45° as possible. The formula is in much the same form as that used above for the Hooke's joint.[1]

ILLUSTRATIONS, TOPOGRAPHICAL SURVEYING.

Profile Sketches from Field Note-books.

Montana N. T. Survey—

Madison River.
Jefferson River.
Missouri, from Spokane Ridge, looking north-east and east.
Smith River Cañon, looking north.
Dearburn River Cañon and Bird Tail Butte.

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[1] See "Electric Testing," by H R. Kempe, art. Tangent Galvanometer, p. 22.

Maps of the N. T. Survey—

The head waters of the Missouri, two sheets.
Forest map, Yakima region.
Soil map of the Yakima and Colville region.
Sketch map, showing route of pack-train.
Crazy mountain sheet, office scale.
Yakima sheet, „ „
Colville region, „ „
Missouri, from Stubbs' River to Gun River.

U.S. Coast Survey—

Typical topographical drawings, $\frac{1}{10,000}$
„ „ „ with sketches.
Comparison, Coast Survey, tracing from field sheet, scale $\frac{1}{10,000}$; same reduced to scale of publication. Map of St. Croix Island from Champlain's Voyages, seventeenth century; sketches of plane-table party.

U.S. Geological Survey—

Typical maps, on scale of publication, twenty-five sheets; scales, 4 miles, 2 miles, and 1 mile to an inch; contours, 20 to 250 feet interval.
Seven photo reproductions of p. t. sheets on scale of field work, 1 : 30,000.
Trigonometrical connection of stations on p. t. sheet of scale, 1 : 12,000 or 1,000 feet = 1 inch, showing 100 feet contours.
Profile, Hoosac mountain, showing top of Greylock in distance, two ends of base.
Profile, Greylock mountain.

LAKE MONO REGION SURVEY, BY WILLARD D. JOHNSON, U.S. GEOLOGICAL SURVEY.

Area 1,665 square miles—45 × 37 miles. Shading by sketch contours, with elevations (by vertical angles and aneroid) from which contours of 200 feet vertical interval were interpolated. Four months field-work entirely by intersection method, with plane-tables. Maximum range of elevation from 6,500 to 13,500, or 7,000 feet.

Party of four men, two of whom (packer and cook) managed base camps, from which, with one assistant, I radiated on trips of one to four days, light packed.

Four saddle animals and four pack animals. On side trips, half that number of each. Total cost of field-work of four months, $1,500 (about £300); including expenses to and from the field, enough to bring cost to $1 per square mile (4s. 2*d.* per square mile).

Scale of field sheets, about 1·6 mile to an inch, or exactly $\frac{1}{101.826}$; publication scales $\frac{1}{250,000}$ and $\frac{1}{125,000}$ (4 and 2 miles to 1 inch). Lake Mono, lying exactly in the centre of the map, was systematically sounded by one hundred and three measurements of depth. Lake nearly circular; greatest diameter, 15 miles; area, 85 square miles; greatest depth, 200 feet.

Positions of soundings were recorded by means of two plane-tables operated in concert—one from a single central station, on an island near the centre of the lake, and the other from a series of stations around the lake shore. On account

of the size of the lake and the mirage, communication between the boat and the stations, by signalling, was not attempted, but the position of the boat was noted at equal-time intervals, by lines of direction on each table (taken, of course, simultaneously), from which the course of the boat was afterwards plotted by intersection (on a third sheet) of the two systems of lines.

A time record was also kept of the soundings in the boat, and these were then interpolated between the time-marked intersections.

These courses plotted very neatly among the islands and along the shores, without, apparently, getting out of place.

The vertical angle work was supplemented by use of two barometers (aneroid), read together along the lines of travel. The resulting profile net was not referred to a base barometer for adjustment, but was connected with the points of the primary system, as those points were occupied, and adjusted thereto when they were computed.

A sketch of topographical forms by horizontal line shading upon the plane-table sheets was conducted simultaneously with the work of location, and this was progressively bettered as the interspaces between locations were diminished.

The work was done upon two sheets with broad margins, and was spread in opposite directions from a common initial base, which was a line between two marginal peaks dividing the area in half.

The scale, though arbitrarily fixed by the assumption of a length on paper for this line, was not determined in the field, but provision was made for its ultimate determination by the location of the points of one of the primary triangles of the transcontinental triangulation of the Coast and Geodetic Survey.

Only one of these points fell upon the map, or even upon the paper; the two others were afterwards located by convergence to intersection of numerous lines, beyond the margins. The scale, however, determined from one of these sides applied equally to all, thus putting the work to a severe test.

In addition to the usual detail of topographic work, data relating to old shore lines, and the margins of the ancient ice sheet were also collected.

The office work, though scattered over a considerable period, really occupied one man but sixty days. The expense of office work may be put at $300. Up to the time that the work went into the engraver's hands it may be said to have cost $2,000 (about £400).

In Vol. x., No. 233, of "Science," July 22nd, 1887, will be found an account of an interesting experiment, the determination of the height of a moving cloud with a plane-table, by Mr. H. L. Smyth.

Discussion.

Mr. Bruce. Mr. Bruce, President, in moving a vote of thanks to the Author of the Paper, said he believed it was the first on the subject that had been read at the Institution.

Mr. Pierce. Mr. Josiah Pierce, Jun., thanked the meeting for the kind manner in which the Paper had been received. In its preparation he had no intention of raising any controversial argument about other methods of surveying. He was proud to see present a number of well-known gentlemen who could speak about topographical surveying. He had come to the meeting principally to learn, and not to teach anything new, and he was sure that whatever was said by those who honoured him by taking part in the discussion would be of permanent value. He desired to thank the authorities at South Kensington, and the various well-known instrument makers, for permitting a very valuable collection of instruments to be exhibited in the room adjoining the library.

General Walker. General J. T. Walker, C.B., said he must honestly confess that though he had been familiar with the plane-table for the last thirty or forty years, he had just heard a great deal about it that he never knew before. In India plane-tabling had been practised for about a century. The surveying officers were in the habit of employing a perfectly simple plane-table, and in all the diagrams exhibited he saw nothing approximating to it. Perhaps the nearest was Plate 3, Fig. 7, but that had a ball and socket arrangement which the Indian plane-tables had not. This latter consisted ordinarily of a board 24 inches by 30 inches, to the bottom of which was attached a brass female screw into which, from below, passed a male screw that clamped it to the tripod stand on which the table rested. The stand was different from any of those shown in the diagrams, and was simply a braced tripod stand made as rigid as possible. In all the arrangements shown by the Author, the object appeared to be to convert the plane-table into a universal instrument. In India nothing of the kind was attempted to be done. The instrument was only used for the purpose of filling in details in ground which had already been either trigonometrically surveyed or traversed. There were two entirely distinct systems of operation for survey work in India. First, there was the Topographical Survey, pure and simple, which rested on a trigonometrical basis; and, secondly, there was the Revenue Survey, a topographical survey which was conducted

General Walker.

over all the rich plains of India. In the system of government in India, the village was the unit, and the most important thing was to determine the exact periphery of each village. That was done by traversing with a theodolite and chain, fixing a number of points which were used as the basis of plane-tabling subsequently carried out on scales of 16 or 32 inches to the mile for cadastral work. In these operations the alidade employed was simply a ruler with a pair of sights, as exhibited by Fig. 5 (p. 199). Alidades with telescopes, as represented by Plate 3, Figs. 1 and 2, were never used. The levels were determined by a separate instrument, as Abney's spirit-level, and, for contouring, water-levels were employed. It was a matter of great importance in operations in India to have instruments so simple that natives on very small salaries, men who had had no education whatever in surveying, could be readily taught to do all the work that was required, and such instruments had been successfully used in carrying out very elaborate surveys. The water-level used for contouring simply consisted of a couple of vials turned upside down, the mouths being connected by a tube of gutta percha or tin. The plane-table was a most admirable survey instrument, employable with very great economy of labour. Instead of making field-sketches, and entering a record of the whole of the work in a field-book, to be plotted out after returning to quarters, the measurements were plotted directly on the table *in situ*, thus saving labour, and enabling various details to be plotted on the spot which might not have been entered in the field-books. The economy was therefore very great. The accuracy depended on the plane-tabling being performed within the limits of the skeleton of fixed points. In America the instrument appeared to be used for extension, but in India it was confined solely to filling-in, and that made an essential difference, for thus much greater accuracy could be attained. The Author had said that no climate was less favourable than that of England for an extended survey with the instrument because of its hygrometric variations affecting the paper of the table; but so long as the paper expanded or contracted equally in all directions its changes were immaterial for work done by the system of laying off rays; they only became material when linear measurements had to be plotted on the paper, and the plane-table system of working by intersection of rays was departed from. In India, whenever a plane-table sheet was projected, a scale was invariably projected on it, and therefore, when the paper expanded or contracted, the scale expanded or contracted to a similar extent, and this has generally sufficed to meet the changes caused by hygro-

metric variations in India, where there was greater variety of climate than in England. One advantage of the plane-table was, that the way of using it could be speedily learned by natives of little or no education. When Colonel Holdich was employed on the Afghan Boundary Commission, he had not sufficient surveyors to do the work, and he was able to turn his clerks, who had never before done any surveying, into very tolerable plane-tablers, and to get very fair work out of them after a month or six weeks' training. General Walker.

Lieut.-Colonel T. H. Holdich, R.E., said plane-tabling was thoroughly well-known as applied to the ordinary topographical work in India, and to the Revenue Survey; but within the last twenty-five years there had been a demand for a new sort of plane-tabling, which might properly be termed geographical. The first exploration work had pretty nearly come to an end, and something more was now wanted than the mere route surveys of the men who first went over the ground. To meet this want, recourse had been had to the regular system of Indian plane-tabling, and it had been found quite as adaptable to that class of work as for the ordinary topographical and military maps of the country. Of course, the surveyors could not claim to succeed in attaining such accuracy as was attained in the plains of India; but still, it was regular surveying, based on the same system, with a theodolite-triangulation, and then topography, by means of the plane-table. Throughout all their work, they had adhered to triangulation first and plane-tabling afterwards. It appeared to him that the difference between the American and Indian systems was one of degree only. It was a question of drawing the line where precise triangulation ended and graphic triangulation began. In India the triangulation was carried further than in America. If a plane-table was supplied with a sufficient number of fixed points, the surveyor was comparatively independent. He could begin with a very much rougher instrument; and this, to a certain extent, justified the roughness of the instruments to which General Walker had alluded. Fine instruments were really not wanted. In frontier work the topographers were subject to great vicissitudes, and a plane-table might meet with accidents, so that they could not afford to take instruments of such refinement as those he had seen in the room adjoining the library. A simple deal board, with a tripod stand, answered all their purposes, so long as there was a sufficiency of triangulation on which to base the topography. Although he was not permitted to allude in detail to the work on the Afghan frontier, he might say that there the Lieut.-Colonel Holdich.

Lieut.-Colonel Holdich.

two systems fell in with one another. The Russian topographical staff worked with graphic triangulation only, and trusted to the determination of the extreme points of the survey by means of the astronomical latitude and chronometrical longitude; but the English staff tried to carry triangulation, by means of the theodolite, from India up to the frontier, across from the Persian frontier to the Hindu Kush, and back again to India. Whilst working along the frontier, the English topographers were supplied with quite sufficient points to work their plane-tables on the regular Indian system. General Walker had mentioned that it was possible to turn indifferently trained men into topographers with very little instruction, and Colonel Holdich was able, with three or four half-trained topographers in the field, one or two of the officers being always occupied in triangulation, in two years to cover an extent of ground which was measured by 120,000 square miles. Of course they did not claim to have completed such mapping as would be seen on the American maps, but they had left out nothing that was of distinct military or political importance in topographical delineation. He thought that military engineers were very much indebted to the Author for the new light he had thrown on a subject, with regard to which there had been exceedingly little literature.

Colonel Sir Chas. Wilson

Colonel Sir CHARLES WILSON, K.C.B., K.C.M.G., R.E., had personally no experience of the plane-table. It had not been adopted upon the Ordnance Survey, but it was in very general use on the Continent. He believed it had been used on the national survey of every country in Europe, with very satisfactory results as regarded accuracy. In Germany the custom was to have at least three trigonometrical points on the plane-table sheet, and generally from three to five points, and the plane-table was then used for filling in. The cadastral survey of England was now completed, and he was afraid that the plane-table would not be very useful in the revision recently commenced, except perhaps for some of the 6-inch work in the Highlands of Scotland.

Captain Sankey.

Captain H. R. SANKEY, R.E., observed that, at the beginning of the Paper, the plane-table had been referred to as an instrument of precision, and it was stated that its accuracy was only limited by the scale to which the map was drawn. He presumed that statement would only apply to maps whose scale was not greater than about 6 inches to the mile, but not to maps on a scale such as $\frac{1}{2,500}$, or $25\frac{1}{3}$ inches to the mile, which was the scale on which the cadastral survey of Great Britain had been drawn. One map had been mentioned in the Paper as having been surveyed on a

scale of $\frac{1}{2,500}$, namely, that of Wurtemburg, but it was also stated that for publication a reduction was made to a scale of $\frac{1}{50,000}$. The cadastral survey of England was published on the same scale Captain Sankey.

FIG. 12.

FIG. 13.

as that on which it was surveyed, and that, of course, made a great difference in the accuracy needed in the plot. The method employed for this cadastral survey was the straight-line method. He com-

Captain Sankey.

pared the two methods by means of two sheets of the $\frac{1}{500}$ plan of Birkenhead. On one of these sheets (Fig. 12) there were shown the various chain lines that had been run to obtain offsets for plotting the detail. It would be observed that several long chain lines had been run and only fixed some minor detail. These "waste" lines, which were dotted, would not be required with the plane-table. In that case, therefore, the plane-table would no doubt be more economical. On the other sheet (Fig. 13), which represented another part of Birkenhead, there was a great mass of detail, and the chain lines had not been shown, because they were so numerous, and also very few of them were "waste" lines. He would like to ask the Author whether, in such a case, plane-tabling would be economical, considering the great number of stations that would have to be employed. In the case of the cadastral survey of England, it was not sufficient to simply sketch in the details, the hedges and footpaths, &c. It must be perfectly accurate to within a foot. Therefore it seemed to him that in that case plane-tabling would not be more economical than the present straight-line method. It might be said that the detail could be plotted by traversing with the plane-table, but traversing with a plane-table could surely not be more accurate than traversing with a theodolite, which had been rejected on the Survey as being insufficiently accurate. The most important point was, however, still to be noticed. It had always been considered that one of the great reasons for the accuracy of the Ordnance Survey Maps was the system of subdivision of labour, and the numerous checks that were brought to bear on every man's work. The surveyor who chained and measured the offsets for the details was simply told where the trigonometrical stations were; he was not told the length from one station to another, he had to chain that himself, and send in the details to the office. If it was found on plotting that his measurements differed more than two links in a thousand from the trigonometrical distance, he had to re-chain the line. If the main lines were found accurate, the subsidiary lines were plotted, and if any had been measured wrongly the error would be detected, and such lines would have to be re-chained. The detail was then plotted in the office, and finally subjected to several examinations in the field. With the plane-table one man was responsible for the whole of the work, and it appeared to Captain Sankey that there was a capital chance for "fudging." As regarded the number of men required to work the plane-table, he saw from the Report of the Coast Survey of the United States that it was best to employ five men, though it had been used by two.

In the straight-line method of the Ordnance Survey, two men did the work in the field, one man in the office did the plotting, and a fourth acted as examiner. The examiner would probably have the same pay as the head man for the plane-tabling, and the pay of the others would be also about equal, therefore there was one man to the good for the Ordnance Survey. He noticed that the educational value of the plane-table had not been mentioned in the Paper. When a boy at school in Switzerland twenty years ago, the first surveying he ever did was with a plane-table. He had to draw a church, and he could remember the very clear notion it gave him of surveying, by being able to compare the plan of the church as it was plotted with the church itself; by other methods a learner worked somewhat in the dark, and the plotting was done at home where a direct comparison could not be obtained. Therefore for educational purposes the plane-table was an excellent instrument. He wished to ask the Author how plane-tabling would work for contouring purposes in connection with the telemeter, and whether such an arrangement would be economical, working on the 6-inch scale. He also mentioned that a plane-table, by Breithaupt, had a spring fixed underneath to the movement, and it was said that any blow or undue pressure on the plane-table had, in consequence, far less effect. Captain Sankey.

Colonel G. H. Bolland, R.E., said he could add nothing to what Sir Charles Wilson, General Walker, and Captain Sankey had said. He had had no practical experience with the plane-table, but he had been much gratified by what he had heard. Colonel Bolland.

Mr. John Coles referred to another purpose to which the plane-table could be put. He did so as one who had to instruct intending travellers. He had found that, for people who had no knowledge of surveying at all, the handiest instrument, and the quickest they could learn to survey with was a plane-table, but he also found that when the objects were distant they were unable to align the plain sights on them; he had known many men who could not do this at a greater distance than 1 mile. Therefore, without knowing anything about the elaborate plane-table of the United States, he had added a telescope to his alidade, which, being fitted with a graduated vertical arc, enabled him to fix positions in latitude with considerable accuracy, and also longitude, having the advantage of knowing Greenwich time from a chronometer. In the case of travellers who might not have Greenwich time with them, this addition to the alidade would make it quite possible to fix their positions astronomically by meridian altitudes and the method of moon-culminating stars. Mr. Coles.

Mr. Coles. The difficulty was to get the telescope into the meridian. He managed to get it to move pretty accurately in the meridian by observing equal altitudes of stars east and west of the meridian, as having only a small arc he was unable to use the system of high and low stars, because he could not get altitude enough. When, however, the Author came to England and showed him his alidade fitted with the solar compass (which he had incidentally mentioned in the Paper) he thought that it was the thing he wanted, but instead of using it as a solar compass he used it as a stellar. With the stars the declination practically did not vary, and he had been able by that means to fix his telescope, having properly levelled his table, so near the meridian as to get the longitude more closely than by a single set of lunar observations. That was a great advantage, because a traveller could thereby fix his points, which if in elevated positions would enable him with the plane-table to map a considerable area, and many who were not at all capable of keeping a proper field-book would in that way be enabled to give a very good map of the country through which they travelled.

Colonel Ardagh. Colonel J. C. Ardagh, C.B., R.E., said that on several occasions it had been his duty to make up his mind what class of instruments should be used to carry out rather extensive boundary surveys, and on all such occasions he had come to the conclusion that a tolerably large transit-theodolite was the first thing to have, and for details nothing could come up to a plane-table. He was most firmly convinced of that. As a British officer he had had extensive experience with all kinds of surveying instruments, and he did not think he had ever turned out such good, reliable, rapid work with any other instrument as with the plane-table. With imperfectly educated persons, such as Colonel Holdich had referred to, the simplest instrument was the best. For the instruction of officers in general, in military surveying, the prismatic compass had been selected. It was indispensable to select an instrument which an officer might reasonably be expected to possess, and to carry about with him. That was the chief reason the prismatic compass had been chosen. The use of the plane-table in its elementary form was also taught, and it was that form which, in practice, was most useful. A plane-table could be extemporised most easily. A small drawing-board screwed on an ordinary tripod, such as was used for photographic cameras, gave all that was necessary; and a common four-jointed 2-foot rule, with the outer joints turned up, made an alidade good enough for rough work. He had surveyed with an elaborate plane-table, and

also with a very elementary one, and he thought it was much better to have a theodolite than a plane-table weighing 40 or 50 lbs. If a plane-table weighed only 10 or 15 lbs. it would serve all necessary purposes. It was a matter of surprise to him that the practical engineers and surveyors of this country had not used the plane-table very much more than they had done, and he strongly recommended it to their notice. Colonel Ardagh.

Professor HENRY ROBINSON, in reference to the Author's opinion that the plane-table should be used within certain practical limits, hoped that he would make some definite statement as to what those limits were. During the last few years he had occasion to study the use of the plane-table, and to employ it as part of the work of the students at King's College for whom he was responsible. In his own particular work in this country he had had no occasion to use it, but he was satisfied that the time had arrived when a wide field was opened for the useful employment of the various appliances which were exhibited. The plane-table was now far removed from the class of rough and clumsy instruments, and might be called an instrument of precision. The danger was that it might be relied upon over too wide a field without the necessary triangulation stations. In this country there was no occasion to use such an appliance, because the main points had been fixed by the Ordnance Survey; but younger members of the profession, in foreign countries where very little information was obtainable, might study the Paper with advantage, and the instruments exhibited in connection with it. Even in many parts of this country a great amount of work was carried on by the theodolite and chain at an enormous cost, and he was sure that much of the work now done in that way could in future be done by the stadia and stadia-rod, and that the plane-table, the tacheometer, the omnimeter or telemeter were well deserving of attention. There was no doubt an element of risk in the fact that no record of the work was preserved. A great amount of it was done on the drawing-board in the field, and if any accident happened from wet weather, or if the element of "fudging" came in there was no check upon it. But he was confident that the instrument as a whole had a wide field of application for contouring, taking soundings, and many other purposes. He was pleased to think that the Author, who was an old King's College student, had so well come to the front. Professor Robinson.

Mr. GEORGE KILGOUR said that the subject of the use of the plane-table and telemeter in topography was one in which he Mr. Kilgour.

Mr. Kilgour. took great interest. He regretted that, from the fact that he only arrived in England from South Africa by the last mail, he was unable to treat in an adequate manner a question of such vital importance to the engineering pioneer. He would confine his remarks, as much as possible, to the additional instruments that he usually employed in conjunction with the plane-table proper; and would further limit them to the uses of these instruments of topography as applied to the laying out means of communication, mining, and other engineering works. But he wished to state with regard to the plane-table itself, that he rarely if ever put it exactly to coincide with the station, preferring to select the most convenient spot in the immediate neighbourhood, plotting that spot on the plan, and working the alidade from such point as axis. The first rapid survey that he made by these methods was in the winter of 1866–67, when he was employed by Sir John Fowler to prepare plans and estimates of certain lines over the "St. Gotthard" pass in the Alps, the chief object being to ascertain to what extent the summit tunnel could be shortened by steep gradients working up the side of the valleys of the Reuss and Ticino. In that work he had for a colleague Amadeo Gentilli, a well-known Austrian engineer, who had already had much experience in such surveys, and who he believed was the first to make them from photographic panoramas taken at each station. The work had to be done during winter in all sorts of weather, and on the roughest of grounds; for not only was it required promptly, but they had to learn, as the late Mr. Scott-Russell, also associated with the matter, expressed it, "what snow could and what snow could not do." Inspection of the ground showed that the ordinary plan of setting out and levelling was out of the question; whilst, owing to the forests with which the greater part of the slopes were covered, points on the scarp could rarely, if ever, be seen from two points in the valley; so that triangulation and the employment of the plane-table in the usual way was negatived. The following plan was at length perfected and employed during the entire survey, which practically extended from Altdorf to Giornico, a distance of some 90 kilometres (56 miles). A second horizontal wire was fixed on the diaphragm of the transit at such a distance from the centre one as to subtend about 4 metres (13 feet) at a distance of 1 kilometre (1,094 yards). A staff was then designed, being made by the village carpenter; this consisted of a strong red pine lath, about 16 feet long, to which were attached three circular tin disks, coloured black and white in alternate quadrants, placed at 2 feet, 6 feet 6 inches, and 11 feet

from the bottom, whilst a fourth disk was attached to a slide playing on the staff between the upper fixed disk and the top, attached to a 1-inch-square rod about 11 feet long. A movable sight square to the lath, by means of which it could always be held square to the line of sight, completed the instrument. An even and straight piece of road was then selected, and on this a length of 1 kilometre (1,094 yards) was most carefully chained, marks being left at each 10 metres (32 feet 9 inches). The staff was then held successively at each such mark, and the movable disk raised by means of the rod until coincidence between it and one of the fixed disks was obtained on the double wires of the transit instrument set up at zero on the line, such coincidence being fixed by marking the sliding-rod exactly opposite to a fixed mark on the staff; these marks or rather scales were made on the three visible sides of the sliding-rod, thus forming three scales which respectively referred to the three fixed disks. Three focal lengths were marked on the transit, to be employed respectively for the three fixed disks, which, of course, came into play consecutively as the distance increased. It would be evident that with this staff the staff-holder, directed by the observer at the transit, had the means of ascertaining his hypotenusal distance from such transit, the particular fixed disk on which coincidence was made being indicated to him by flag-signal. A survey line and levels were then carried up the valley stations, being fixed in convenient points about $1\frac{1}{2}$ kilometre (1,640 yards) apart, and the transit instrument was set up at one of them. The staff-holder, who took with him a note-book (having certain pages marked with concentric circles representing even distances from the station, and radiating lines 10° apart), a prismatic compass, aneroid, Abney's level, stout staff, a couple of flags for signalling, and the usual Alpine equipment of a couple of guides, rope, ice-axe, &c., went to a point on the hill somewhere about the level that the line would pass, easily ascertained by the aneroid, where the staff would be plainly visible from the transit instrument; he fixed the short staff, placing the compass on it to settle, and holding the staff upright aligned the sight on the transit, and signalled to the observer there. The transit observer next directed the movements of the upper disk until the necessary coincidence was obtained, and signalled which of the three fixed disks had been employed. He also took the horizontal bearing and altitude of the point, booking them with the time of observation. The staff-holder then took the direction of the transit from the compass, plotting with this and the hypo-

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Mr. Kilgour. tenusal distance the spot in his note-book, which thus replaced the "plane-table." He further took, with the Abney level and with the compass, the greatest up and down slope and their bearings, as also the bearing of the contour either way. Further, any important points not visible from the transit were surveyed by compass and tape, and carefully noted, the contours being also sketched on the note-book plan, with streams, cliffs, and other topographical features; also the time of each observation was recorded. In the evening the observations were collated and the true distances and altitudes worked out, and on the first hopeless day, of which there were many, the work was plotted, and a contour survey prepared. The time occupied in such work was about 1 kilometre per day on a range of level of over 300 metres (1,000 feet) on the mountain side, and about the same time was occupied in plotting. When the work was about half completed, Mr. Gentilli was compelled to go to Vienna on urgent business, and his place was taken by Mr. Hodgson, an assistant of Sir J. Fowler's, who threw himself at once into the spirit of the work, and proved a most valuable colleague. The result was that, before the following summer, plans and sections and estimates for several lines were submitted to Sir John Fowler, together with exhaustive accounts of all the avalanches and other special difficulties to be contended with. The next survey of this class that he made was that of the northern half of the Bahiuda Desert, also under instructions from Sir John Fowler. This was done with the plane-table pure and simple, and he had for a colleague Mr. Bakewell. This work was done from stations on the line as staked out, and at the rate of about 2 miles per day, preparing the permanent plan occupying about one quarter of that time. The large plan which he exhibited was a survey of the Nile between the first and second cataracts, which was done to beguile the monotony of a journey to the northern terminus of the proposed Soudan Railway, of which he then had charge. This survey was made from the deck of his steam-launch by means of a plane-table kept constantly in the meridian by the compass, the hills, &c., being put on in the usual manner by means of the "alidade." The distances travelled were plotted by time scales, the value of which was ascertained as follows, the plan, he believed, being then original. Two lines of sight near the bow and stern of the steam-launch were laid down square to its axis, and the distance between accurately determined. Some prominent near object, such as a solitary palm-tree on the bank, was then selected, and timed by means of the chronometer at both lines of sight for full speed, half

speed and dead slow. This was repeated at different points of the river, and the accuracy attained was most remarkable. Every night careful observations were made for latitude and longitude, and, these being laid down on paper to the required scale, the eidograph was employed to correct any small differences of length between such points. The survey, about 200 miles in length, occupied about five days, and the final plotting somewhat longer. The method he had finally adopted for finding the latitude and longitude involved only a few minutes' calculation, required next to no astronomical knowledge, and no mathematics higher than rule of three. He placed the theodolite in meridian by means of circumpolar and zenith stars, a method requiring, say, half an hour in the northern hemisphere, and possibly double that time in the southern. That gave at once latitude and local time, *i.e.*, longitude. When he wished to get the former with great accuracy, he took subsequently one or two north and south stars, operations (the instrument being in the meridian) occupying only two or three minutes each, whilst for half the month he could check his chronometer by moon and culminating stars, an operation taking about ten minutes, and requiring next to no calculation. He also, at times, did the same by eclipse of the first or second satellite of Jupiter, but as the results were not accurate unless both disappearance and reappearance were taken, which usually meant sitting up half the night, the plan had its disadvantages. A chronometer, though not indispensable, was a most useful auxiliary, as the half-second tick enabled the observer to work alone, and to keep his eye constantly on the star or the moon, whilst crossing the wires. The last surveys he had made were route maps across South Africa from Beaufort West, the then terminus of the Cape railways, to Delagoa Bay, *viâ* Kimberley, Pretoria, Origstadt, and the Drakensberg, riding, driving, and walking. Here, again, he employed his book as plane-table, keeping it in approximately the same meridian by means of the shadow cast by a small special but very simple instrument in the book. This method, during sunshiny days or moonlight nights, was, he found, incomparably preferable to using the compass, which required rest to steady it, and was subject to grave variations near the basalt extrusions so constant over all Africa. The reduction of such shadows to the true north was readily made subsequently from Davis's tables, the main distances were checked by trocheameter whilst driving, and by latitude and longitude, and the rate of work was dependent only on the rate of travelling. The levels were of course taken by aneroid. He regretted that he had been able to place no finished plans of

Mr. Kilgour.

Mr. Kilgour. this work on the table; but his note-books, instruments and plotting-scales employed were there. Such plans prepared by him were supplied by the War Office to Colonel Warren during the Bechuanaland expedition, extending, he believed, from the Orange River to the Hart, about 150 miles. But to return to the plane-table, he found that the addition of a good telemeter, such as the one exhibited, was invaluable, being merely a double-wire circular micrometer attached to a good telescope. To use such a one it was advisable to determine by experiment the value of the divisions throughout, and then have a staff constructed. This value was obtained by attaching two tin disks, like those described above, so that coincidence of the wires with the centre of the disk having been made, reference to the column of reciprocals in Barlow's table at once gave the hypotenusal distance. He also used his transit instrument for the exact bearing and altitude, plotting the corrected distance down on the plane-table at once, together with a note of the difference of level, by means of the diagonal scale on the table. Subsequently, if time allowed, he calculated out all the points by the system of rectangular co-ordinates. That system was not as well known as it deserved to be. It was extremely simple, especially if the entire survey were kept in one quadrant; and by its means any portion of a survey, no matter how small, could be plotted without the necessity of laying down the lines, whilst numbers of problems of frequent occurrence in surveying could be thus solved in the simplest manner. The only other special instrument he used was the camera lucida. By means of this little instrument panoramas might be made at each station, in which the angular bearings were absolutely correct, and thus any omitted bearings might afterwards be measured, and the contours put on with great readiness. The instrument might also be employed in enlarging and in reducing plans, and was not subject to the distortion of the camera obscura (or photographic camera). His plane-table fitted on to his ordinary mining tripods, and was recessed to take a drawing-pad, which he found extremely convenient. He levelled it with a circular bubble and ordinary screw-plates. To his ordinary transit he had added a diagonal eye-piece, a striding-level, and a small reflector, so that scarcely anything was required, save the ordinary surveyor's equipment. In conclusion, he would warn the young engineer who took up with such sketch surveys that it must be done *con amore*, and, though seldom aught but a labour of love, might prove of use to his country; he would give an instance regarding the plan on the wall. In 1878, he was asked to present a copy to the Royal

Geographical Society, of which he had the honour to be a Fellow. During the Egyptian troubles of 1884, such copy had a place of honour given it on the screen in the hall of the Society, and was, he had been informed, exclusively used by the War Office during the Gordon rescue expedition. To summarize, valuable instrument as he considered the plane-table to be in broken ground and fine weather for topographical work, it was, in his opinion, but one in a considerable series of appliances that should form part of the tools of the engineer in unsurveyed countries. Mr. Kilgour.

Captain C. McG. Bate, R.E., said that the plane-table had hitherto been recommended to him as an instrument for rough drawing, and general rather than one of minute accuracy. With regard to its rough work, he would mention the sketching-board, introduced into the service by Colonel Richards, Instructor of Topography at the Staff College, which was made on the principle of the plane-table. The board was strapped on to the arm of, and worked by, a man on horseback. The straight-edge was simply directed towards objects, there were no sights, and yet the drawings, for rough work, were remarkably correct. He could only account for it, by supposing that the plus inaccuracy counteracted the minus inaccuracy, so that the general result was right. At any rate, for military purposes, the instrument was a very useful one. Another purpose for which the plane-table had been used, and had been highly spoken of, was finding the ranges of distant objects, and he had been told by artillery officers, and the officers of his own corps, that the plane-table was a far better range-finder than had been introduced, not because it was more accurate in every case, but because it was more generally accurate, and there was much less likelihood of great blunders, than there was with the range-finders used in the service. His range-finder was a field-glass with a small plane-table fixed on it. It had three scales, which plotted the triangle from which the range was obtained. The scale on which the triangle was shown was very small, about $\frac{1}{4}$ inch to 100 yards, but the accuracy obtained had been between 0·5 and 0·8 per cent. Reference had been made to the telemeter, and it was stated, that the maximum error was 0·1 yard in 100 yards. That, however, was only up to 600 yards, and the telescope was not capable of being used beyond that distance for accurate surveying. He should like to know the percentage of error between 600 yards and 3,000 yards, that being a very important matter in regard to range-finding. He understood that if it could be told from the telemeter what that Captain Bate.

Captain Bate. percentage of error was, when using a graduated rod held upright, it would be the same with two telescopes, with a base between them the same length as the rod, both telescopes being directed on one object, instead of one telescope directed on a graduated scale. For range-finding, the telemeter would be the most perfect instrument, if it were possible always to find in the distance an object of known dimensions; but that was almost impossible. In the Government range-finders the instrumental error had been fixed at a maximum of 2 per cent. up to 3,000 yards, with a base of 60 yards. With the infantry range-finders, in which the maximum instrumental error was 1·5 per cent. for 1,000 yards, the actual error, including that of observation and also error of base, was found to be 11·1 per cent. under fair service conditions. Yet if he was correct in estimating the telemeter as giving 0·1 per cent. up to 600 yards, the range-finder with a very short base had, he thought, the advantage. Range-finders had often been used for quick surveying, where it was impossible to use any other instrument; for example, in the case of Capt. Brotherton, R.E., in the face of the enemy at Laing's Nek, and the survey was very successful. Distances had also been measured by noting the time taken for sound to travel. That was found, in the first instance, to be sufficiently accurate, and it was thought to be a great success; but when three or four men at a distance were firing together, it was impossible to tell which sound belonged to which puff of smoke, and that led to the rejection of the instrument. All other range-finders had been formed simply on the principle of triangulation—with the isosceles triangle—the right-angle triangle—the double triangulation with the right-angle triangles—the exterior and interior angle of any triangle—in fact, every system of triangulation had been used, and with a certain amount of success; but all these range-finders would give place to one which could obtain the range with a single observation. That range-finding was a subject of very great importance; indeed, the result of the war in the Transvaal was due to the fact that the Boers were better able to estimate distances than their opponents were. A new rifle was to be introduced into the service, one of its main points being its low trajectory, hitting point-blank at 500 yards, so that it would be unnecessary to estimate distances within that range.

aptain Boyce. Captain E. J. G. Boyce, R.E., said that as he was at present in command of one of the Divisions of the Ordnance Survey, he naturally took a great interest in the instruments described in the Paper. He had himself used the plane-table on several occasions

in surveying, and he had found it extremely useful in Submarine Mining. For such rapid surveys as had been described, and for local work or for estimates, and for fixing points and levels, the instrument ought to prove invaluable; but for Government work, like that of the Ordnance Survey, he thought it would have some objections. In the first place, its accuracy depended upon the skill of a single manipulator, who was of course always liable to error. Then there was the absence of checks which the public had a right to expect in any Government survey, or one accepted by a court of law. He would ask the Author what was the largest scale for which the plane-table would be adapted, and how, in the case of a survey of a large tract of country where a great number of plans would have to be joined together, he would assimilate the edges and show accurately all the detail shown in the Ordnance plans? Either he would have to adopt a very large amount of chaining and off-sets, or the working plan would be such a maze of intersections that it would be extremely difficult for the operator himself to understand it, to say nothing of the ultimate draughtsman who would be required to draw the plan. He thought there was a very great objection to the instrument in the English climate, there being very few days in which it could be taken out for accurate work. It was generally conceded that it would be very difficult to plot or draw any work accurately in the field. Any inaccuracies that might exist on the working plan would be intensified in the drawing. He did not see how that difficulty could be overcome, because it was always extremely difficult to transfer any plans owing to the errors in drawing, and errors due to the contraction of the paper. In regard to cost it was not easy to arrive at any comparative estimate, because so much more depended on the scale and accuracy of the survey, and the amount of detail shown, than on the actual number of acres surveyed; but he thought that the cost would increase in a rapid ratio in the plane-table with the increase of scale. That was not so materially the case with a chain survey. He might be permitted to say something in regard to the system of checks considered necessary in Ordnance Surveys. In the first place, the plans were all drawn on a very large scale, $\frac{1}{500}$, or $10\frac{1}{2}$ feet to the mile, and in agricultural districts $\frac{1}{2,500}$, or $25\frac{1}{3}$ inches to the mile. With such scales it was possible to obtain a high degree of accuracy in the drawing, an error of 1 link being clearly shown on the plan. The main surveys were based on the triangulations made with Ramsden's great theodolite. From that, secondary and tertiary triangulations were made, cutting up the country into a series of

Captain Boyce.

Captain Boyce. very small triangles. The points of these triangles were accurately laid down by co-ordinates or sheet-line distances. The sheet-lines on the plans, containing 960 acres, were carefully laid down with a special instrument, and the points were scored on the plans from the direct distances obtained. The several plans were next placed accurately together, and the triangles joined in. One or more surveyors were then told off to chain accurately each of the triangles; each surveyor sent in his record of chaining, which was carefully plotted, all the main lines and split lines being placed on the plots. Any line not coming within the limit of error laid down was rechained by the surveyor, until it plotted within the limit of error, which was 2 links in 1,000. It would thus be seen that the chaining acted as a check on the triangulation. As soon as the chaining had been declared accurate, all the points of intersection on the plots were carefully traced. All the corrected field-books were then handed over to another plotter who plotted the whole of the detail, and his work was checked by a third person with a tracing of the plot. After the plan had been passed it was divided into six portions, which were all carefully traced off in black, some errors being purposely inserted on the tracings, which were called distortions. Those traces were then sent out to the field and checked by the examiner, who made all the necessary corrections, supplied all the ornament, and collected the names and descriptions. The whole of the work was afterwards examined in the same manner by another man, who was held responsible for the accuracy of the trace. The traces then came into the office, where they were looked at by an officer who had to see that there was no careless work anywhere. Afterwards the plotted plan and the traces were handed to the draughtsman, who transferred any corrections that had been made on the traces, and penned in the outline. They were then passed to the typers for the names and the ornament to be typed on the plans. The plans and documents were then passed into the hands of the plan examiner, who went through the whole of the plans, comparing them with the traces, and other documents, seeing that all the remarks had been properly attended to, assimilating the edges, and making any observations that he considered necessary. An officer then took the plan out into the field and satisfied himself of its accuracy. Afterwards the plans left the Division and went to the Levelling Division, where the levels were put down from an entirely independent source, thus forming another check on the accuracy of the plans. They were then sent to Southampton to undergo a very severe

test by several men. All the documents were carefully examined, and after the remarks had been attended to, the plan was finally reduced to a 6-inch scale by photo-zincography, so that a perfect representation of the original manuscript plan was secured. With the plane-table a great number of those checks must be necessarily wanting. The working plans were in pencil, and liable to be obliterated and damaged, besides being liable to errors. He thought that a small plane-table might be advantageously used for such purposes as the Government examination, but he did not think it would do for any Government survey to be based entirely on the plane-table. Summarizing the objections to the instrument, the work was dependent on one man, who was liable to error; there was a difficulty in plotting in the field; there was a difficulty in transferring the working plan on to the fair plan, owing to the shrinkage of the paper and other causes; its unsuitability in this climate; there was a want of portability if the instrument was required for a large scale survey; and the greatest disadvantage of all was the want of sufficient checks and records. Captain Boyce.

Mr. B. H. Brough said that the Author had neglected to state how the plane-table compared, in economy, with its youngest rival, the transit and stadia. Everything that could be done with the plane-table could also be done with the theodolite, and that was the reason why the plane-table was almost unknown outside the limits of great national surveys, where expense was a secondary consideration. Even in the United States the plane-table was being largely superseded by the transit theodolite used in conjunction with the stadia or telemeter. During the last few years in that country 15,000 square miles had been surveyed by that method, and Professor J. B. Johnson stated that in Pennsylvania alone 3,000 square miles had been surveyed in that way.[1] In the vicinity of working mines, or where land was valuable, the work was carried on with great precision and at extremely moderate cost. The theodolite was now made in a very portable form, and it had been brought to a high state of perfection, so much so that even with the 3-inch transit-theodolite reading to single minutes, as accurate results could be obtained as with an ordinary plane-table. The latter instrument, on the other hand, still retained essentially the same form as that given by its inventor in 1590. All the improvement that had been made in Mr. Brough.

[1] 'A Manual of the Theory and Practice of Topographical Surveying by means of the Transit and Stadia,' p. 51. New York, 1885.

Mr. Brough. its construction with the object of rendering it more precise had added to its weight, and made it more expensive. And, besides being heavier and more difficult to transport than the theodolite, other disadvantages were connected with it. It took longer to set up, and the orientation was an extremely tedious process. It was also impossible to keep the plan clean, and the accuracy of the results largely depended on the way in which the paper was mounted on the board. If there were any furrows in the paper serious inaccuracies might result. It was, therefore, necessary to mount the paper in an extremely wet state, and to bring it in close contact with the board by covering the latter with white of egg beaten up with water. Lastly, there was the disadvantage of having no record but the field-plan, which was always liable to be spoiled by accident in a storm. In fact, it was only when he had had a little experience with the plane-table in the Harz mountains and in Sweden that he fully realized how extremely frequent storms were. Surely the advantage derived from plotting in the field must be more than counterbalanced by the increased cost, field-work being much more expensive than office work. Against all those disadvantages there were only two advantages, namely, rapidity and the fact that the ground was sketched from nature, so that any glaring errors were at once detected. But, valuable as the Paper was as the only English monograph on the plane-table, he thought it failed to controvert the opinion, expressed by Rankine and many other authorities on surveying, that, though very useful for surveying in cases where minute accuracy was not required, as in military and topographical surveys, the plane-table was unfit for engineering purposes.

Mr. Walmisley. Mr. A. T. Walmisley said that when he first saw the title of the Paper it occurred to him that there was novelty in anti-quarianism; but he was thinking of the old form of plane-table about 16 inches square, without the additional elaborate optical arrangements shown by the Author in the diagrams. These additions enabled a magnifying power to be obtained, by which distinctness of vision was secured. He thought that the plane-table in many cases was useful for military surveying, but he agreed with Mr. Brough that it was not applicable to civil engineering purposes. In this country, subject to rapid changes of climate, engineering surveyors liked to keep the paper, books and map, which they carried in the field, as much as possible under cover. When a sketch was made and the dimensions were booked, the field-book was at once put into the pocket, the map being rolled up after having been kept open as short a time as possible. With the

plane-table, the sheet of paper was perpetually exposed to the action of the atmosphere. Perhaps as much accuracy could be obtained by the use of the plane-table as when working with the prismatic compass. The great advantage secured by the employment of a theodolite, was that it enabled the surveyor to set the instrument exactly over a station point, an advantage which, for civil engineering purposes, it would be unadvisable to part with. The theodolite, too, was much more compact to carry about than the plane-table. As the Author had alluded to various forms of tripod heads, he had exhibited one or two forms which were not generally known.[1] The first was called the Hoffman tripod head. The upper plate was made with a circular curve concentric with the half-ball and socket joint, and the elevating screws were supported on a sliding plate. In addition to that, the upper plate, which carried the telescope, could, after shifting into the desired position, be clamped or loosened by means of two adjacent parallel plate screws, the ordinary setting of the instrument being finally adjusted by moving opposite plate screws in the usual way. Some persons preferred to work with three screws instead of four, in parallel plates. A great advantage was secured by three screws, since they must rest on the lower plate, whereas with four screws the instrument might simply be resting on three screws, and one screw might be above the plate, in which case jerking and inconvenience might arise. Messrs. Adie had an improved form of parallel plate in which, by means of a slot, the central portion was prevented from being strained when setting up the telescope level, by means of opposite parallel plate screws. There was another form of locking plate with three screws, as made by Adie. It was important to have the wooden legs which supported the tripod made solid and heavy enough not to be subject to jerk and to the action of the wind. There was also greater steadiness secured when one lug was arranged upon the leg, and two lugs upon the top connecting-piece, upon which the instrument was screwed. Two other systems were shown. In one case the two lugs were shown on the top piece, and in the other case they were upon the leg. Another form of stand, made by Messrs. Troughton and Simms, consisted of two plates one above the other, which allowed a space of 3 inches in which the plumb-bob and vertical axis of the instrument could be accurately set over the station-point. The plates were shifted and set by pivot action. Another curious form of tripod head, known as the Jahn tripod

Mr. Walmisley.

[1] *The Builder* vol. lii. 1887. *Passim.*

Mr. Walmisley. head, had only one screw and a hinge-joint. It was set in one direction by a wedge action, and in the other by means of a single screw, but the objection to that was, that in revolving the telescope upon its vertical axis, the wedge-shaped portion must be held in position by the hand, because there was no clamp provided. Another form, to which he would allude, was that of an instrument made by Messrs. Elliott, called the Doering joint tripod head. Two vertical arcs at right-angles to one another were provided, each fitted with clamp screws and tangent screws. The vertical gimbal joints worked within one another as in a ship's compass. The Pastorelli tripod head, with a telescope mounted upon it, had a very short form of bar under the telescope. The tripod head could be shifted in roughly setting up the instrument. The diagram of Adie's combined level and theodolite would explain itself. The Tacheometer and the Omnimeter both served to arrive at the measurements of distance. His own experience was that, in spite of all the various useful optical instruments that were made, there was no survey so accurately executed as when the chain alone could be used in the open country. Wherever he could dispense with optical or angular instruments, and simply make use of the chain for measuring and connecting the base lines, he preferred to do so.

Mr. Gribble. Mr. T. G. GRIBBLE noticed that a great deal more had been said about the plane-table with reference to topographical than to railway surveying, and some remarks had been made tending to show that the plane-table was not suited to railway work. In many ways, however, it was suitable, and he knew of instances in which, in spite of the rigorous stipulations of Standing Orders, railway surveying in this country had been carried out very successfully with the plane-table. He knew that Mr. Walrond Smith had made railway surveys with that instrument when very greatly pressed for time. In one case a message was sent from the party in the field that the work could not possibly be done in time; but Mr. Smith went out with the plane-table and finished it, carrying his plans through Standing Orders, notwithstanding very severe opposition. His instrument was provided with rollers to carry a continuous plan. He adopted the plan of chaining the centre line, and filling in the intersections of hedges and so on, as he went, with the plane-table. The great point that had been gained by the present Paper was, in his opinion, that the plane-table had been brought to the consideration of engineers generally, who he believed would find out many ways of using it for themselves when once they possessed the instrument even in its simplest

form. He had himself taken the instrument to the Sandwich Islands, where he had found it of very great use in extremely rough country; he had combined it with the transit theodolite fixed with stadia hairs. It was used for filling in details, and at times for triangulating, when certain conditions demanded it. The plane-table was fixed over one of the pickets, which had been previously fixed by the theodolite, within, say, 100 feet distance from the buildings, which were too much detailed to be put in with the stadia measurements; radiating lines were then taken from the picket, and the details were thus filled in rapidly. It was quite true that nearly all that could be done with the plane-table could be done also with the telemeter-theodolite; but it could not always be done so quickly. Of course, as to the accuracy there could be no question about the superiority of the latter, especially in levelling, as with the telemeter-theodolite an independent check could be got when taking the backsight. In regard to chaining, there were many cases in which the telemeter-theodolite would enable work to be put in a great deal more accurately than it was possible to do with the chain, as in very sloping grounds, ravines, and the like. Mr. Coles had remarked that he was able to get the longitude by means of moon-culminating stars with a telescope on the plane-table. It was a trite saying that the next best thing to having a good instrument was knowing how to use it; and the remark was perhaps truer with regard to the plane-table than it was with regard to any other instrument. If anyone bought a plane-table in order to get the longitude by moon-culminating stars, he would be considerably disappointed. There was only a small telescope on the plane-table, and moon-culminating stars were of so small a magnitude that the observer would perhaps find it difficult to discover them even with a large telescope. No doubt, when he knew how to use the plane-table with the skill possessed by Mr. Coles, he would be able to do many things with it, but it was doubtful policy to try and make the plane-table a universal instrument. As to the form of telemeter which would be most useful to military engineers, it should be remembered that the civil engineer could get his base at the point observed; the military engineer had to get his base at the point of observation. A man might be sent out by the civil engineer with a pair of disks or a graduated rod to a place where an observation was wanted; but if the military engineer sent out his man to the point observed, he might not come back again. As yet there had not been much success in the precise measurement of a base at the point of observation. The two principles of

Mr. Gribble.

Mr. Gribble. base, one a fixed base with a varying angle, and the other a varying base with a fixed angle, ruled the two kinds of telemeters to be used. He had combined the two in his telemeter-theodolite, having movable hairs which acted on a fixed base. They were moved by two sliding diaphragms, and the fixed base was a pair of disks. Within the limits of observation of a graduated rod, he used stadia hairs, fixed horizontally in the diaphragm. Beyond these limits he used the movable hairs actuated by a micrometer screw similar to that adopted by Messrs. Elliott Brothers in their army distance-measuring telescope. It had been for a long while the aim of surveyors to obtain both these operations in one instrument, and he believed this object had been to a great extent attained. Two telescopes, one of 20 power and the other of 40 power, were provided in the case, for alternative use.

Mr. Pierce. Mr. Josiah Pierce, Jun., in reply, said that the members who had listened to the discussion, and had had the unusual opportunity of hearing, from the lips of distinguished men present, accounts of the economic value of the plane-table in many fields of topographical work, could no longer doubt that the plane-table was in existence and valued in every branch of topographical surveying. He could not quote higher authorities, and nothing had been more gratifying than the presence of such authorities to speak for themselves, and the kind and friendly interest shown in the subject. The problem attempted was to describe the plane-table in its best form, a mapping instrument of precision, and it was impossible in the Paper to do more than give a brief sketch of its application.

The questions which now appeared to be best worth considering were in what form, and within what limits, would the plane-table be of value to the engineer? It was not an easy task to eliminate, from the mass of valuable information which was given, the essential facts of greatest value. It would be remembered that the plane-table was described as used for the geographical survey of large areas, for mapping limited areas in great detail, as a convenient filling-in instrument, and as a handy sketching-board for military reconnaissances. Something of value could be gathered from all, but what was really required was a reliable instrument which, in the hands of a careful man, would give accurate results over the range of scales commonly adopted for engineering maps. General Walker had stated that "it was a matter of great importance, in operations in India, to have instruments so simple that natives on very small salaries, men who had had no education whatever in surveying, could be readily taught to do all the work

that was required, and such instruments had been successfully used in carrying out very elaborate surveys." The problem under consideration was one of a very different character, the construction of engineering maps with the greatest possible rapidity and accuracy, with a very limited number of men. In the United States, contact with the natives in the wilderness was to be avoided, and the most economical results had been obtained with the plane-table in the hands of men thoroughly well up in topographical work, and in the use of other instruments; and much of the success and accuracy of the United States Geological Survey maps, carried out over areas where every problem of surveying had to be considered, was due to the *esprit de corps* of a very limited staff of topographers. He had taken it for granted that an engineer might require, under certain conditions, a map of a considerable area on a small scale, or, more commonly, maps on a large scale of a limited area, and in either case the plane-table appeared to be the most economical instrument for the purpose, under favourable conditions of climate and atmosphere. General Walker had stated that the hygrometric effect on the paper might be neglected when it expanded or contracted equally in all directions, if the method of intersecting rays alone was used. It was true that it might be neglected if the map was checked by many trigonometrical points, and the horizontal projection of the map was alone considered; but in nine cases out of ten, on a purely topographical map, horizontal measurements were only taken to establish altitudes, and were referred to a common scale. It could not be expected that the paper would be uniformly affected by changes of moisture or heat. That might easily be proved by experiment, by drawing on a piece of paper a large circle, and testing its diameter in several directions, after exposure on a damp day, or before a fire. The most accurate results were obtained on well-seasoned mounted paper, exposed for only a few hours on the plane-table board, shaded from the sun, and carefully rolled away after each day's work in an air-tight tin case. The topographers of the United States Geological Survey had done plane-table work on a small scale, with accuracy, within the area of a large primary triangle, the secondary and tertiary triangulation on which the detail was based being constructed in the process of drawing the map. Thus in reality the graphic triangulation was a contracting one from the large bases of the primary system, with diminishing chance of error, and in the construction of the map it was impossible for a single error in the position of a trigonometrical point to escape detection, under the severe geometrical criticism applied

Mr. Pierce.

Mr. Pierce. in orienting the sheet. This did away with the possibility of fudging or doing inaccurate work, as a single unchecked error would alter the scale of the map in all directions, and render it worthless. The foregoing results were of very great value, as showing that within a limited area, where, as far as the map was concerned, spherical excess could be neglected, the plane-table alone could be employed. He had been content to suggest that, as far as the limits of the board were concerned, a map could be constructed on the plane-table with accuracy, although there had been many instances where, by careful work, graphic triangulation had been carried over several sheets. It was sufficient, however, to consider the case of one large sheet, and that for ordinary cases two or three trigonometrical points would be projected on it. Where a larger number were established, there seemed to be no reason why a large plane-table should be used. With that limit he still held to the key-note of the Paper, that a map could be constructed on the plane-table of any scale, and with a degree of accuracy only limited by the scale. Captain Sankey had assumed at the outset that Mr. Pierce had referred to scales of about 6 inches to 1 mile. He had had no intention of conveying that impression, but it might have arisen from an examination of the list of maps to be exhibited. He had made several efforts to obtain from America plane-table maps of far larger scales, but without success. On the Continent, although the common scale of plane-tabling was 1 : 25,000, in many instances it was ten times as great, or the exact scale of the Ordnance Survey, and the maps had been accepted in courts of law as correct even for cadastral purposes. But he assumed that the cadastral map was but a convenient form of record of areas surveyed, and that a topographical map was a representation of the *terrain* or natural features, untrammelled with the record of areas or property boundaries, beyond the limits of the scale, which placed an economic value on the unit to be used in field measurements. On a map of the scale of 4 miles to 1 inch, which could be considered the limiting scale in one direction, a penny postage-stamp would cover an area of about 12 square miles. It could readily be understood that important stations would frequently be within a fraction of 1 inch apart. On large scales cases might arise where the stations would be equally close. Captain Sankey had desired to know if in such cases the plane-tabling would still be economical, and had exhibited for comparison an Ordnance Survey map of a part of Birkenhead, on which the tie-lines were so numerous that they were not shown. Mr. Pierce could only say that, as far as the map alone was concerned, plane-

tabling was accepted as the most accurate, rapid, and economical method of field-work, however minute the detail, on account of the many operations of field-work and office-work avoided, and of the opportunities, in any stage of the construction of the map, of checking its accuracy without delay or expense. That it was possible to produce elaborate plane-table maps, of great accuracy, would be evident to all who had examined the specimens on the scale of field-work; and, as an instance of city work, he might refer to the map of Paris as a wonderfully good example, although outside the limits of topographical surveying. The system of careful checking of all work on the Ordnance Survey rendered the results most accurate, and, for cadastral purposes, the most economical. But a comparison of methods with those of topographical surveying was out of the question, owing to the different problems involved. On the United States Coast and Geodetic Survey system each point was located in altitude, as well as position, and referred to a common datum of mean high-tide. The stadia-rod had been successfully used for fifty years, with great economy, and he thought that no American engineer would use any other method of contouring, except where a very narrow strip of side-slopes was required on railroad work. The use of the telemeter, or graduated rod with the alidade, and of the latter as an instrument for trigonometrical levelling, necessitated a specially-designed rigid plane-table, having an accurate levelling movement, and adjustment in azimuth. In such an instrument stability had precedence of portability; but, on account of its high cost and great delicacy, its use outside of Government circles was not common. The recent improvements and simplicity of the instruments used on the United States Geological Survey, constructed especially for easy transportation, if they did not meet a long-felt want, should at least create a demand. A simple and accurate instrument was all that was required. The student could easily learn the first principles of plane-tabling in a few hours, and it was worthy of note that Professor Geikie, in his recent book on the teaching of geography, had suggested that the elements of plane-tabling should be taught in primary schools. The student need not be discouraged at apparently slow progress, because the result of each measurement and each error would be exhibited in the complete record of the work on the sheet. If he desired to fudge, let him do so, and reap the full benefits of his experience. So much had been said, in the course of the discussion, about the absence of proper checks in plane-table work, that it would be well to state briefly those commonly applied. These questions could not have

Mr. Pierce.

Mr. Pierce. arisen had it been possible, within reasonable limits, to have dwelt at greater length on the problems involved in trigonometrical surveying. Captain Boyce had given an admirable account of the methods adopted to secure accurate results on the Ordnance Survey, but it should be observed that the chief problem involved was mensuration, while that of topographical surveying was the representation of relief. Both had in view the same end, the construction of an accurate map, and among the requirements of the latter, mentioned on the first page of the Paper, was the one that, from any point on the map, the angles subtended by other points should be appreciably the horizontal projection of those which would be obtained between the same objects in nature. This was the key of modern plane-tabling, and its successful application in practice, in the problem of orienting by known points, checked the accuracy of the map in all its dimensions; while the test applied in linear surveying was linear measurement on the ground in but one or two directions. That geometrical test of the accuracy of the map could be applied at all times, without expense or delay, but only by an accurate instrument. No suggestion was given in the Paper of the personal equation; it only appeared desirable to point out that a sharp-edged tool existed, which should not be allowed to grow rusty or be abused. The addition of a levelling movement and alidade did not complicate a simple sketching instrument, but rendered possible an infinite number of applications not mentioned by Rankine and other authorities on surveying. The old "Prætorian Mensula" of 1590, still in existence, oriented by compass, was no more to be compared with one on which angular errors could be neglected, than was the prismatic compass with the modern theodolite. The rivalry between the theodolite and the plane-table existed in England more than three hundred years ago, and could be found in an old folio, the 'Pantometria' of Leonard Digges, published in 1591 in London. Although it was possible to measure any suitable base, and extend a graphic triangulation on the plane-table sheet, the work could not compare with the careful system of basing the surveying on established triangulation of precision accurately projected on any desired scale. Each combination of two points served as a base, and of three a reliable check on the work; while, by method of intersections, each pair of intersecting rays theoretically defined the position of a point with reference to the adopted scale, and a third ray placed beyond doubt the accuracy of its location. Briefly, a practical application was made of the elements of modern projective geometry, and no more accurate test could be applied in

practice than the one adopted. When any doubt existed about the accuracy of the sheet in the course of its construction, the plane-table was set up at some commanding point, whether previously occupied or not, and oriented by any three signals in sight. It was pointed out that an apparently correct intersection would be obtained from three points, even when the figure on the sheet was distorted, but that there would be a serious divergence from the meridian in nearly every case. Hence, if there were only four points on the sheet, three being correctly plotted and one in error, four possible combinations of three points might be taken, from which four positions would be found, only one of which could be correct. Further progress would be impossible without correcting the position of the offending point. Hence the importance of testing the accuracy of the triangulation before detailed operations were commenced. To return to the test, the same law applied equally to all details, however minute or unimportant. A position having been found by any three points, the ruler was laid down on the station point, and any other trigonometrical point on the sheet, and, if correct, the corresponding signal would be seen in the centre of the field of the telescope. In broken and wooded country the importance of having a high-power telescope on the alidade could not be over-estimated, as signals could frequently be found in this way when invisible in an ordinary field-glass. Having tested the accuracy of the position by a fourth signal, details could be checked in all directions, and no serious error could escape detection if this simple mathematical test was applied at all stations. Far from remaining a maze of intersections, details were filled in around each station, and nothing was left to memory. The self-reading or graduated rod was the one commonly used with the alidade, its range being practically limited to about $\frac{1}{2}$ mile, since the cross-hairs, however fine, subtended an appreciable angle, and hid the minute graduations seen in the image of the rod. More accurate results could be obtained in traversing with the transit, using a rod with movable disks or targets. Notes would, however, have to be taken by the rodman, and reduced in the office. The plane-tabler required immediate knowledge of the distances measured, and for his purpose the self-reading rod was alone suitable. The false estimation of a few units of length produced but slight errors of altitude, which could be neglected. The necessity of placing an instrument exactly over a station only arose in higher trigonometrical surveying and traversing, and became less and less as the scale was diminished. The largest scales on which topographical surveying had been

Mr. Pierce.

Mr. Pierce. carried out was probably about 100 or 200 feet to 1 inch. The plane-table alone would not be employed, and trigonometrical levelling would be supplemented by more accurate methods. The foot would become a convenient unit, and the stadia-rod could be applied with accuracy for a range of between 200 and 300 yards. With little experience it was impossible to meet all the points of the discussion, but finally, with regard to cost per square mile, it could only be safely said that it varied approximately as the square of the scale, increasing per square inch of map as the distance between located points became greater, and such questions as transportation, &c., arose. The cost per square inch of the plane-table maps of the Continent had been nearly uniformly about 10*s*. To guard against possible injury to the field-sheets, the details of each day's work should be traced and transferred to office plans of the same scale. The triangulation alone secured the accurate junction of a series of sheets, which in all cases had wide margins overlapping their neighbours, on which marginal notes were traced and tested. With regard to the practical limits to the use of the plane-table, it had not been found economical in either very flat or densely-wooded country, and was only at its best in the special field of topographical surveying.

Correspondence.

Mr. Bakewell. Mr. W. N. Bakewell said that his experience confirmed that of the Author so far, that in a suitable climate, with a good plane-table and distance-measuring alidade, in open country, a contoured map could be made on any scale, in every respect equal in accuracy to maps obtained by chaining and levelling in the usual way, and at a fraction of the cost. The rougher the country the greater the economy; so long as the staff-holders could get about without difficulty all surveys could be made with equal facility, the rapidity of execution depending entirely on the amount of detail. In 1876, he was in charge, for Sir John Fowler, K.C.M.G., of the survey for the projected railway from Dongola to El Fasher, a length of 925 kilometres (575 miles), through a practically unknown country. With two English and two Egyptian engineers, on an average 6 to 8 kilometres per day were set out, levelled, and chained. Mr. A. Meley, a Swiss engineer, with his plane-table kept well up with the work, surveyed, and in difficult ground contoured, a width of 1 kilometre, using stadia rods, and in addition by intersections fixed many of the prominent distant

hills. In places where boundaries of property were simply marks on the ground, or such as offered little obstruction to the view, cadastral survey might be economical. In England, however, this was not the case, the amount of detail was too great, and, apart from the climate, surveys could be more expeditiously made with the chain. Here, except for limited areas in special cases, the plane-table could not be used satisfactorily, the paper being so much affected by the dampness of the air. Many methods had been tried to get over this difficulty, cementing the paper on sheets of glass, as done in Hungary, being perhaps the most effective plan, though clumsy and objectionable. The Author had amply described and illustrated the plane-table in its many types. With his remarks about the unnecessary weight of many of them, and the uselessness of the contrivances for correcting the error of eccentricity, he thoroughly agreed. In 1877 he wanted fifty plane-tables for the Egyptian cadastral survey, and had patterns from the best known makers on the Continent. With the exception of those made by Kern, of Aarau, all were much heavier than necessary. As Kern could not make the tables in time, he designed one which, together with the alidade in its box, was an easy load for one man to carry, without sacrificing the rigidity which was so essential. Messrs. Elliott Brothers made the instruments and had adopted the pattern, and supplied others very similar to the Royal Engineers. The boards were pine, grooved similar to the drawing-boards in general use, were light, and they warped very little during three years' work in Egypt and in the Soudan. The addition of a parallel bar to the edge of the ruler of a telescopic alidade added very much to its value. In sighting an object, it required close attention to keep it through the exact station on the paper. With a parallel bar it was only necessary to be within the distance the bar would open, and to use it to draw the required line. With the light plain-bar sight, a pin stuck in the station was a sufficient guide. For small-scale work, if the method of intersections only was used, a very simple apparatus would suffice. In 1872, in the Bahuida desert, the compass being unreliable, he suggested to Mr. G. Kilgour, M. Inst. C.E., the advisability of making a plane-table. He made a couple of sights from the tin of an old box, fixed them on an ordinary 12-inch box-wood scale, and used a camp-table. Of course there were difficulties in levelling and getting in position, but some capital work was done. Other arrangements not quite so primitive would suggest themselves to those who wished to practically test the method without much expense. Where the climate prevented the use of

Mr. Bakewell.

r. Bakewell. the plane-table, some of the well-known telemetric methods of obtaining distances might be employed with advantage. The simplest and cheapest plan was to have two additional webs in the diaphragm of a level fixed to subtend 1 foot on a staff distant 100 feet horizontally from a point, which was the focal length of the telescope in front of the object-glass. Thus, in a 12-inch instrument 101 feet 6 inches from the cone of the instrument, the difference of the readings of the two webs on a level staff, multiplied by 100 (plus 1 foot 6 inches), would give the distance in any other position within the power of the telescope. Probably, however, the webs would not subtend exactly the angle required, but would be within 5 per cent.; the error might be readily obtained by testing measured lengths. The percentage thus ascertained must be added or deducted as required. Opticians seemed to have no difficulty in fixing the webs equidistant from the central one, so that, as often occurred with a level when the central web and one of the others were seen, 200 was the multiplier corrected as mentioned above. The two additional webs might be adjustable at the expense of a new diaphragm. This method, though obviating correction, was liable to get out of adjustment in use, and was not quite so reliable. With a compass in addition, levels might be taken and fixed in any direction, or contours run and surveyed at one operation. The same arrangement might be applied to theodolites, heights and horizontal distances being readily reduced from the observations by means of the ordinary slide-rule, if the staff was held sloping at right-angles to the line of sight; or with a specially constructed rule with scales of $\cos^2$ for horizontal distances, and cos $\times$ sine for heights, when the staff was held vertical. The telescopes of the 5-inch and 6-inch theodolites being of low power, about 300 feet was the maximum distance at which this method could be employed. On one 6-inch theodolite he used these wires up to the limit. For longer distances, Mr. W. F. Stanley fitted for him on the horizontal axis an arm with clamp, against the lower end of which worked a micrometer screw, the head being formed as a scroll. A pointer on this arm indicated the distances without any calculation. A 10-foot rod, or rather marks at 3 and 13 feet on the level staff, were used, the rod being held at right-angles to the line of sight. A filar micrometer might be employed with a staff of known length, divided either to register angles or distances as required. For about ten years he had used one of Eckhold's omnimeters, made by Messrs. Elliott Brothers, with the microscope parallel to the telescope, so that the scale might be read without moving the position. On it was

an arm which would clamp on the axis of the telescope. Through the fork on the lower end (which embraced a block fixed on the standard) screws passed with lock nuts; they were adjusted to give the telescope a movement through an arc subtending 1 foot at a distance of 100 feet. A spring acting on the head of the front screw kept it bearing on the block, in which position the lower reading on the staff was taken; then, by a light pressure with the thumb, two fingers holding the standard, the telescope was directed to the higher reading, and the difference between them multiplied by 100 was equal to the distance. The adjustment for this movement could be checked in a few seconds by the scale. This method was useful up to 500 feet. Beyond that distance, or where a check or greater accuracy was required, the omnimeter arrangement was used, but not oftener than necessary, as reducing the heights and distances occupied too much time. This might be considerably curtailed by dividing the fixed distance from the scale to the axis of the telescope into 1,000,000 instead of 1,500,000 parts; a table of reciprocals could be used for distances, and the heights then found by simple multiplication or on the slide-rule. This might be done by altering the present micrometer screw to $33\frac{1}{3}$ threads per inch, or by reducing the height to 5 inches and using a screw of 40 threads, keeping the divisions on the micrometer head at 5,000 as they now were, but preferably using a 20-thread screw and dividing the head to 10,000; the figures could then be booked as read, without the present risk of omitting a 5,000 division. A description and illustrations of the adjustable diaphragm and slide-rule had been given in a short pamphlet to which he would refer.[1]

Mr. Bakewell.

Mr. R. Bonnin desired to mention that the plane-table had been long employed in France by the Ordnance Staff (*Service du Génie*), and that it had served as the base for the topographical map of Geneva, made in 1838–39, under the direction of General Dufour. Finally perfected by Wild, Professor of Geodesy at the Polytechnic School at Zurich, this method had come into general use since 1843 for all the stages of the topographical map of Switzerland, on the scales of $\frac{1}{25,000}$ and $\frac{1}{50,000}$. Mr. Kern, instrument maker at Aarau, made practical and handy instruments for the purpose. These instruments were of three different dimensions, according to the degree of accuracy desired. The table was fixed by means of three screws on a solid tripod, and an adjustable level enabled this

Mr. Bonnin.

[1] "Der topographische distanzenmesser mit rechenschieber." J. Stambach, Aarau, 1872.

Mr. Bonnin. table to be put into perfect adjustment. An alidade with a ruler, mounted with a vertical circle, with telescope and micrometric apparatus for the stadia, enabled the position of every point in sight to be fixed, both as to distance and height. A declinator gave the orientation of the plane-table. In short, a very simple fork enabled, by means of a plumb-bob, the exact position on the ground to be brought into concordance with that on the plane-table. This method of land-surveying was employed alike in Austria, Germany, and in Italy for topographical maps. Mr. Sprenger, of Berlin, manufactured instruments nearly like that of which he had spoken, and which were generally used in Germany and Austria. Mr. J. Meyer, Chief Engineer of the West Swiss Railways, had published a very complete memoir on this subject.[1] This system had not only been employed for the preparation of topographical maps, but also in railway surveying, as for the St. Gothard by Mr. Wetli in 1865, and, more recently, the passage of the Simplon, between Brieg and Domo d'Ossola. It compared favourably with the tacheometric methods usually followed in France, in that it obviated the necessity of long calculations, the plan was exact, and taken on the spot; the process was therefore more rapid, and small errors and omissions were immaterial, since all was done on the spot, and the station was not quitted until after the points had been definitely placed on the paper and the contour lines drawn. Nevertheless, for great distances, and for the bearing of the principal lines of the plan, he had found by experience, that it did not always come up to the exactitude that should be required for important projects. He thought, then, that the principal points of the plan should be first surveyed with all desirable exactness, whether by a tacheometer or by triangulation with a theodolite, and that afterwards, for filling in the details, the plane-table might be advantageously used. It was the method followed on the Continent.

Mr. Middleton. Mr. R. E. MIDDLETON, in regard to the expense of surveying, thought, that in India where labour was cheap, it would in all probability be more economical to use the simplest and least expensive instruments and labour, while in America it would be preferable to pay highly for the best labour, and in order to minimize the amount of such labour, to use the best and most precise instruments. He considered the Author had fully proved his claim to the plane-table, when used under the conditions which he exemplified, being an instrument of precision. It seemed obvious

[1] Société des Ingénieurs Civils. Mémoires. Paris, 1884, vol. ii. p. 349.

that, given a truly horizontal surface, an alidade, accurate in all its adjustments, and the practical skill required to set the alidade on the object to be observed, and through the station marked in the table, and to plot the results with care, the same accuracy could be arrived at when plotted directly from the instrument itself, as would result if the same observations were made in the usual way with the most reliable instruments, and the information so obtained plotted afterwards, neither more nor less, and that the accuracy was limited strictly by the scale. That such accuracy was nothing very excessive when the scales were small might be gathered from a consideration of the scales used, and the greatest possible exactitude in plotting. The scales mentioned by the Author were $\frac{1}{2,500}$, $\frac{1}{10,000}$, $\frac{1}{20,000}$, $\frac{1}{25,000}$, $\frac{1}{50,000}$, and $\frac{1}{101,826}$. If the greatest possible accuracy, as obtained in plotting, when the work was done to $\frac{1}{100}$ inch was taken, this amount would represent, in the several scales mentioned above, and taken in the same order, 2·17, 8·34, 16·67, 20·83, 41·66, and 84·85 feet respectively. It was obvious, however, that this, being graphic error, the same applied to the map, whether drawn *in situ* on the plane-table or plotted from a field-book. It was not, in his opinion, possible to compare the surveys obtained by the Author with those made in this country by the Ordnance Survey Department. The former were, no doubt, sufficiently accurate for the purpose for which they were intended, being presumably as accurate as it was possible for plotting to make them; but the only record was that contained in the plane-table sheets themselves, and no calculation of areas could be made from them which should be more accurate than would be obtained by plotting from plan; but the field-books and records of the Ordnance Survey enabled that department to give the accurate acreage of every field which had been surveyed, and the work was intended to be carried to such a pitch of exactitude that no error amounting to more than $\frac{1}{1,000}$ was admissible, and therefore it would require a plan plotted to a scale of $\frac{1}{1,000}$, or 63·36 inches to the mile, or an even larger scale, in order to show the full extent of its accuracy. In the same way he did not think the cost of surveying for the topographical maps of America could be compared with the cost of doing a similar amount of work in England by the Ordnance Department. As had been already shown, the objects aimed at were much more extensive in the one case than in the other, and the conditions were altogether dissimilar. In America the surveyor met with an open country, for the most part, with few, if any, fences, thinly populated, and therefore with few dwellings. In Great Britain the whole

Mr. Middleton.

Mr. Middleton. country, except the hilly districts, was intersected with roads and fences, and the dwellings were comparatively close together, and he very much doubted if the work of surveying would be more quickly or more cheaply done with the plane-table than with the chain, while the survey would be wanting in the elements of extreme accuracy for record and calculation which the present system possessed. Considering, however, that the Ordnance Survey of this country had been commenced one hundred years ago, and that as yet a map could not be got, drawn to a larger scale than 1 inch to the mile, for many districts, and that even these were frequently only sketch-maps, it must be acknowledged that there was a good deal to be said on the American side of the question. If the United States Survey were to be carried on on the same system, how long would the Americans have to wait before they got any map at all? Whereas, by the use of the plane-table, they were able to get surveys of enormous tracts of country done in a very short space of time, and with as much accuracy as the scale employed would admit. While he was doubtful if the use of the plane-table would be generally applicable in this country, he was sure that it was eminently adapted for use in the Colonies, and in countries where the details to be filled in were limited, and where extreme accuracy of calculation was not required.

Major Parker. Major F. G. S. PARKER remarked that in 1869 a very suggestive Paper had been read by Lieutenant-Colonel J. Baillie, at the Royal United Service Institution, on "Photography Applied to Military Science,"[1] in which the employment of photography, as an adjunct to military sketching with the prismatic compass, was advocated. He had often thought it could be applied to plane-table surveys, especially since the dry-plate process had simplified outdoor photographic work; but, so far as he was aware, no action had been taken by the military authorities upon Colonel Baillie's suggestions.

Mr. Thompson. Mr. GILBERT THOMPSON, Geographer to the United States Geological Survey, observed that he had no personal knowledge of the use of the plane-table as a range-finder; yet it was employed, or the principle of the plane-table, namely intersection, was used in artillery practice, as he had seen at Fort Munroe, Va. A base was measured in reference to the line of fire, and a plane-table placed at each end of the base. He was a topographer with the Army of the Potomac, 1863–65, the movements of which were too

[1] Journal of the Royal United Institution, vol. xiii. p. 449.

rapid and irregular for the employment of the plane-table. Some Coast Survey assistants had used one at the siege of Yorktown, Va., in 1862: but the enemy planted a shell under it and blew it to pieces, wounding the assistants. He had surveyed under fire, and considered the plane-table too conspicuous for such occasions; and, except on the occasion referred to, had never heard of their being used under fire. He was not an enthusiast about the plane-table; but he believed it had its sphere of work, as any other surveying instrument. There were sections of country where he would use it exclusively, but for the triangulation and other areas he would discontinue it immediately. Mr. Thompson.

Professor G. L. Vose observed that the plane-table had not been used to any extent in the United States outside the United States Coast Survey and other Government work. He did not think it would be particularly well adapted for railroad work. The employment of the gradimeter and telemeter with the transit had prevented the plane-table from getting into use in some places, where it otherwise might have been adopted. Where a considerable amount of topographical work was to be mapped, he believed nothing could compare for accuracy and economy with the plane-table; but in America it had been so widespread, that very little detail outside the immediate work in hand had ever been indulged in. The United States Coast Survey had done more work with the plane-table than all the other departments put together. Professor Vose.

Mr. A. M. Wellington stated that he had never used a plane-table for railroad topography; but he was disposed to believe that if one were made very light, and especially adapted to the work, it might serve a very useful purpose in certain localities, although in general American engineers took a very narrow strip of ground for topography indeed, and that chiefly for adjusting the finer details of the ground. That a plane-table reconnaissance ahead of the transit party could save much useless and costly survey, however, he was not prepared to admit, unless under very exceptional circumstances. The plane-table was, however, an excellent instrument, and he was satisfied it might well be used more widely than at present. Mr. Wellington.

Major A. W. White, R.A., observed, with regard to surveying by plane-table, that it might be worth while to consider whether a range-finder, or similar instrument, might not prove a useful auxiliary for colonial and exploratory work. A range-finder was very portable, and, if properly used, would measure distances in a straight line, from point to point, up to, say, 1½ mile, with errors not exceeding 1 per cent. of the distance measured. Thus, given Major White.

Major White. a plane-table and a range-finder, the latter would generally save the labour and loss of time in traversing, and would permit an independent check on the entire survey. He had made very satisfactory sketch-maps of unknown country by a range-finder and pocket-clinometer alone, the range-finder giving the absolute distances from point to point, and the clinometer enabling them to be reduced graphically to approximately true plans. Starting from a convenient datum-point A, the distances of a number of conspicuous points, B, C, D, E, etc., were taken at A. This done, a line on the paper was assumed as the direction A B, and the distance A to B was laid off to scale. From B the distances of A, C, D, E, etc., were then taken, which furnished a series of intersections determining all the observed points visible from A and B. Such work might be corrected and extended by proceeding to C, and so on, when each pair of stations would give an independent triangulation. He should say that a plane-table and range-finder together would produce both accurate and rapid work. Military range-finders were none of them, probably, quite suitable for purposes of civil life, but he should recommend the Watkin field range-finder as the nearest approach to it, and he had no doubt that if there were to be any demand for a surveying range-finder, a satisfactory instrument would soon be forthcoming.

LIST OF INSTRUMENTS, &c.,

IN CONNECTION WITH SURVEYING,

EXHIBITED in ILLUSTRATION of MR. PIERCE'S PAPER, FEBRUARY, 1888.

Contributors.	
C. BAKER	Compass, large, in box.
	Dipleidoscope with compass, by Dent.
	Equatorial, portable, by Harris.
	Level, with sights.
	Plane-table (old pattern).
	Theodolite, small horizontal.
W. N. BAKEWELL	Distance-measurer.
	Omnimeter (Eckhold's) with movable clip.
	Slide rule (Rechenschieber) for reduction of stadia measurements.
CARY AND CO.	Artificial horizon (Captain George, R.N.).
	Compass (4″), prismatic.
	Plane-table (Porter's).
	Sextant (8″) and improved stand.
	——— (3″), travellers.
	———, double box (Captain George, R.N.)
	Station-pointer (8″).
	Transit-theodolite, (5″).
L. P. CASELLA	Aneroid, Field's engineering.
	Declination-Compass.
	Eclimetre (8″ circle divided on silver) with telescope, &c., mounted on straight edge.
	——— on straight edge, with folding sights.
	——— with revolving telescope.
	Hand-levels for use with levelling-staff, dispensing with chain.
	Surveyor's compass, with tangent-scale on sights.
	Transit-theodolite (3″ travellers). ——— ——— (3″) for mining operations. } both very compact.
JOHN COLES	Alidade with solar, for star observations.
ELLIOTT BROTHERS	Cavalry sketching-board (Col. Richards')
	——— ——— ——— (Capt. Verner's).
	Clinometer (Francis').
	Compass, prismatic.
	Omnimeter (5″) and 10 feet staff.
	Plane-table (Chatham pattern).
	——— (Egyptian pattern).

	Range-finder (Captain Bate's).
	Stadiometer (Howlett's) and chain.
	Surveying-instrument (Edgworth's).
J. Graham Gribble, Assoc. M. Inst. C.E.	Level, adapted (Abney's).
	Telemeter-theodolite (7″).
George Kilgour, M. Inst. C.E. . .	Equatorial for astronomical observations, with sextant and attached mercurial horizon.
	Plane-table, camera lucida (telemetrical and co-ordinate scale).
	Solar azimuth, dials, &c., for flying surveys.
	Theodolite for astronomical observations.
Negretti and Zambra.	Perambulator, for measuring the length of roads, &c.
	Theodolite, (8″ Everest's), fitted with improved locking plates, &c.
Josiah Pierce, jun., Assoc. M. Inst. C.E.	Alidade with solar.
	Errors in azimuth, model to show.
	Hooke's joint-problem.
	Maps, &c.
	Plane-table (Johnson's).
	Three-point-problem models.
Royal Geographical Society . .	Plane-table.
Science and Art Department . .	Jähn's Vielmesser.
W. F. Stanley	Alidade.
	Two plane-tables (Indian pattern).
	Ruler with raised sights.
	Telemetrical level.
J. H. Steward	Plane-table, very light military.
	Range-finders.
Troughton and Simms	Centering-stand, open frame.
	Level (16″) and stand.
	Tacheometer (4″) and stand.
	———— staff.
	Transit-theodolite, (6″).

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21 February, 1888.

GEORGE BARCLAY BRUCE, President, in the Chair.

The discussion, upon the Paper by Mr. Josiah Pierce, Jun., on the use of the Plane-Table, occupied the whole evening.

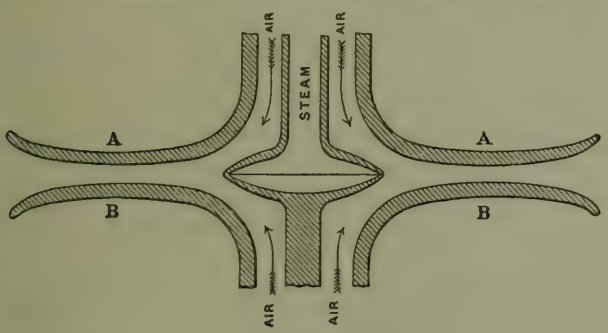
Sect. II.—OTHER SELECTED PAPERS.

(*Paper No. 2253.*)

"Experiment with a Steam-Exhauster or Blower."

By George Brunton, M. Inst. C.E.

It having been stated by Mr. Carl Siemens,[1] M. Inst. C.E., that, in the case of pneumatic dispatch-tubes, an exhauster or blower working at a pressure of 70 lbs. steam was superior in economy to a good steam-engine, the Author recently took occasion to test the accuracy of the assertion. The Siemens' blower, of the form used



in the experiments with pneumatic tubes being no longer procurable, the Author devised an exhauster of the section shown in the accompanying Fig. In this instrument the steam escapes between the lips of two cupped disks 2 inches in diameter, which can be placed in close contact, or be opened to any extent not exceeding $\frac{1}{4}$ inch. The mixing-chamber A B is also formed of two adjustable disks encircling the blower at such a distance as to allow of the latter being opened to its full extent. It was found that the best results were obtained by a steam-opening of $\frac{1}{80}$ inch, and a distance between the air-disks of $\frac{3}{32}$ inch, with a pressure of 75 lbs. per square inch in the boiler, and a full opening between it and the blower. The latter was fixed on the top of a cylindrical case of wrought-iron, the lower open end of which was immersed in the water of the River Cochin to the depth of a few inches.

[1] Minutes of Proceedings Inst. C.E. vol. xxxiii. p. 10 *et seq.*

On an average, the space exhausted was 50 cubic feet. As thus adjusted, the blower raised the water till it choked itself, or through a distance of 5 feet, in from ten to eleven seconds from the time the steam was admitted. As in descending, the water took twenty-one or twenty-two seconds to reach its normal level through the air-passage of the blower, a valve 2 inches in diameter was fixed in the top cover of the case, which was opened the moment the blower choked, and the steam was shut off. The water then took five seconds to descend. It was noticed that the first $2\frac{1}{2}$ feet of water were raised in six seconds; the second $2\frac{1}{2}$ feet in four seconds. On taking count of the fuel and water consumed, it was found that the blower was twice as expensive to use as a good steam-engine and pump, and the Author decided not to pursue the matter. Shortly afterwards, however, he received a copy of the Paper read by the late Sir William Siemens before the Institution of Mechanical Engineers on the 2nd of May, 1872,[1] in which it is stated (conclusion 1), "That the quantity of air delivered per minute by a steam-jet depends upon the extent of surface-contact between the air and the steam, irrespective of the steam-pressure, up to the limit of exhaustion or compression that the jet is capable of producing." This induced the Author to repeat his experiments. The diameter of the case being 3·65 feet, the area was as nearly as possible 10 square feet, the height was 6 feet, and the lower open end was immersed 3 inches in the river, the boiler being on the bank about 20 feet distant. At each lift the water rose till it choked the blower. With the steam-outlet set at $\frac{1}{100}$ inch, the limit of exhaustion was 64 lbs. pressure of steam; that is, at 63 lbs. pressure, the water rose to within an inch of choking, but would rise no higher. The pressure in the boiler was 86 lbs., at which pressure the water was raised hundreds of times in from nine to ten seconds, as regularly as if by clockwork, to a height of 5 feet 9 inches; with an evaporation in the boiler of 1 cubic foot of water for every thirty-five lifts. The Author then stopped firing, and found that for every decrease of pressure there was an increase of time until, at 64 lbs. pressure, forty seconds were required, or five times as many as at 86 lbs. This further experiment was repeated many times; but always with the same result, for which reason the Author is constrained to dissent entirely from the conclusion of Sir William Siemens quoted above.

[1] Institution of Mechanical Engineers. Proceedings. 1872, p. 97.

(*Paper No. 2252.*)

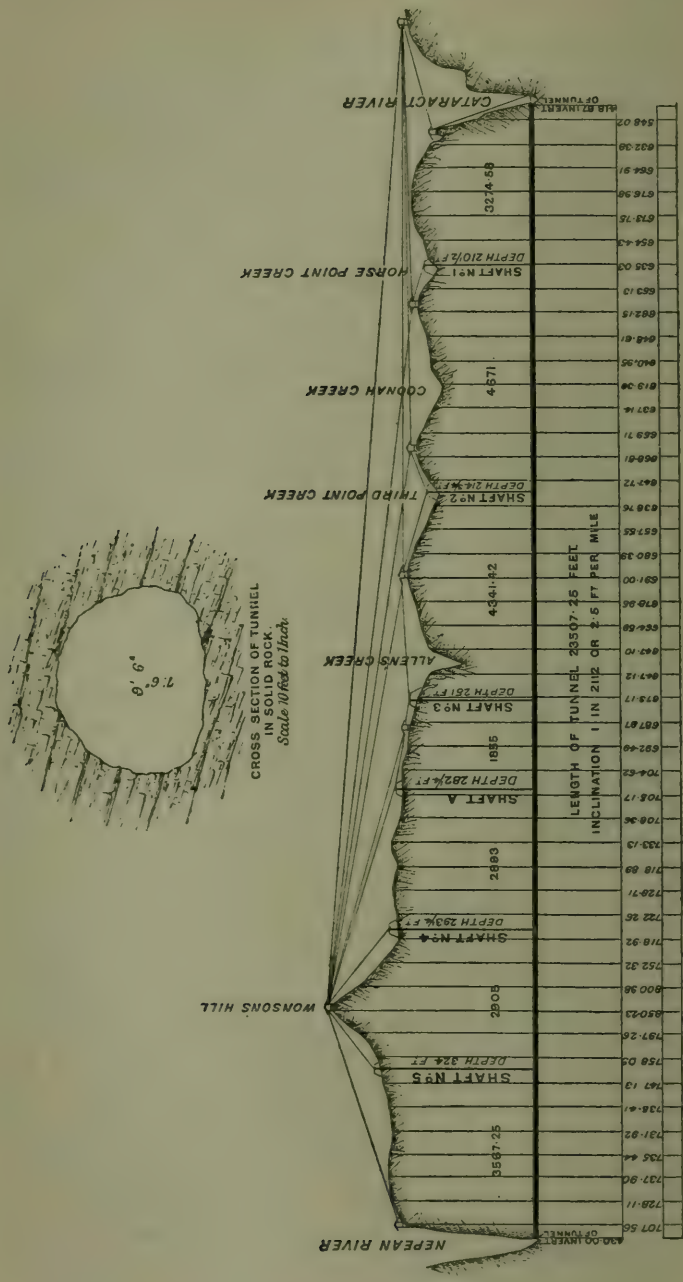
"The Alignment of the Nepean Tunnel, New South Wales."

By Thomas William Keele, Assoc. M. Inst. C.E.

(Abstract.)

The Nepean Tunnel is 23,507 feet, or 4·45 miles long. The bases at the east and west ends were 254 feet and 212 feet respectively, situated at the bottoms of precipitous gorges nearly 300 feet in depth. There were six shafts admitting of only 12-foot bases, the depths ranging from 210½ feet to 324 feet. The tunnel is a conduit for water and was cut at once to the full section. The length between shafts Nos. 2 and 3 was 4,341 feet, the headings meeting at a point 3,018 feet from shaft No. 2. The error in the alignment was ⅝ inch, and in the levels ¼ inch.

The tunnel is situated at the head of the works for supplying Sydney with water. The inlet taps the Nepean River immediately below its junction with the Cordeaux River at an elevation of 430 feet above sea-level. The outlet of the tunnel opens on to the Cataract River, a few hundred feet below Broughton's Pass crossing. The tunnel is 7 feet 6 inches high from invert to crown, and 9 feet 6 inches wide at the broadest part, the normal cross-sectional area being 57·84 square feet. The inclination is at the rate of 2 feet 6 inches per mile, and it is capable of discharging, when running full, 97,000,000 gallons of water in twenty-four hours. Several streams cross the line of tunnel, but only one of importance, at 11,947 feet from the inlet. The average elevation of the surface over the tunnel is 260 feet, attaining 425 feet at Wonson's Hill, the highest point. The geological formation is Hawkesbury Sandstone. A trial survey of the line was made in 1869, and when it was decided to carry out the Nepean scheme, a more detailed survey was entrusted to Mr. G. A. Tillett to enable the contract plan and section to be issued. Before the contract was let, the Author was requested to make an independent set of levels over the whole line. When compared, the sets of levels were found to differ by only ½ inch at the end of the line, but about the centre the difference was 2½ inches. The two gentlemen above mentioned then went again over the ground


CATARACT RIVER
HORSE POINT CREEK
COONAH CREEK
THIRD POINT CREEK
ALLENS CREEK
WONSONS HILL
NEPEAN RIVER
SHAFT N°1
DEPTH 210½ FT
SHAFT N°2
DEPTH 214¾ FT
SHAFT N°3
DEPTH 261 FT
SHAFT A
DEPTH 282¼ FT
SHAFT N°4
DEPTH 293¾ FT
SHAFT N°5
DEPTH 324 FT
3214·69
4671
4341·82
1895
2883
2905
3567·25
LENGTH OF TUNNEL 23507·25 FEET
INCLINATION 1 IN 2112 OR 2·5 FT PER MILE
Scales { Horizontal 4000 feet to 1 Inch
Vertical..... 400 }
Datum Low Wat. Water Sydney Harbour
CROSS SECTION OF TUNNEL IN SOLID ROCK.
Scale 10 Feet to 1 Inch.
7'·6"
8'·6"

together, working with separate instruments, and the differences were corrected. A longitudinal and a cross section of the tunnel, showing the general arrangements, are given in the annexed Figs.

The contract having been let to Mr. W. J. Edwards, the work of tunnelling was commenced at both ends. In the first place the centre line was again run with an 8-inch transit-theodolite, and points were established on posts sunk level with the surface, at every important place along the line; bases were also established temporarily in the bottoms of the gorges, to enable the tunnel to be correctly started. On the highest point at Wonson's Hill an observatory was built, which commanded the whole line. The foundation for the column for the instrument was of masonry, 5 feet square, the surface of the stone being 3 feet above the ground. Care was taken not to disturb the original centre point, which was plumbed up through a circular hole in the stone, 1½ foot in diameter, and marked on a brass plate leaded in at right-angles to the line. A weather-board shelter, 12 feet square, was erected over the stone, with doors opening in the direction of the line. The large transit instrument was made by Messrs. Troughton and Simms of London.

Another observatory was built of masonry set in cement mortar at the extremity of the line, across the Cataract River on the high ground about ½ mile beyond the gorge. It was nearly 4 miles from Wonson's Hill, and commanded all important stations on the summits of the hills along the line. The face of the pedestal for the transit-instrument was dressed smooth, and the centre line painted on it with a black streak, 1 inch wide from top to bottom, on a white ground.

A rough timber-shelter, 8 feet square and 8 feet high, was erected over the pedestal, the sides and roof being covered with galvanized iron, and doors were provided opening back and front 5 feet wide. About 50 feet to the rear of the observatory, a background of boards painted white was erected, so that when sighting from any of the stations along the line, the object suspended over the centre point on the stone should be clearly defined. All trees in the vicinity were cut down. At the side of the observatory, and also at Wonson's Hill, a semaphore was erected, consisting of a pole supporting a cross-bar, with pulleys at each end for signalling purposes. After the pedestal was finished, the centre point was transferred from the original mark on a rock a few feet away, to a brass plate similar to the one at Wonson's Hill, let into the top stone. The plate, divided for a space of 3 inches to 20ths

of an inch, was securely leaded in at right-angles to the line, and on this scale the particular division which corresponded with the centre line was marked. Similar scales were invariably used throughout the whole work, both above and below ground, whenever it was necessary to establish a point by plumbing.

On the pedestals the scales were leaded in across the holes, and the plummet was hung inside, where it was protected from wind, and if required the hole could be filled with water to steady the bob. The plummet-wire or steel bar, being suspended from a sighting-frame or tripod, was brought into position while just touching the scale, and the reading could be taken accurately.

The points in the centre line in the Cataract and Wonson's Hill observatories having been fixed, it became necessary to produce this line to the Nepean River, nearly a mile distant. The large transit was therefore placed in position in the Wonson's Hill observatory, the telescope was directed to the Cataract observatory, and the intersection of its cross-wires brought into coincidence with the black line 12 feet in length, painted on the face of that pier. The telescope was then lifted off the Ys, and a bar inserted in its place. This bar was provided with a collar at each end, turned to fit the Ys. A tiny hole was drilled through the centre, and a fine silk thread was passed through the hole, and a small plummet attached to the end and lowered inside the pedestal; after it became steady, the position of the thread against the scale was noted, and if it was found to be off the permanent mark, the plate on which the standards rested was shifted till it coincided; the bar was then lifted off, and the telescope again adjusted on the Ys, till the black line on the distant pedestal was intersected, and so on through successive approximations. At length the telescope intersected the distant mark, and when replaced by the bar, the plummet-thread exactly cut the permanent mark on the brass scale; the instrument was then in adjustment to extend the line. The telescope was reversed and directed to a plummet-cord $\frac{1}{8}$ inch in diameter, suspended from a sighting-frame on the top of a pedestal, built on the edge of the cliff over the inlet of the tunnel; this cord was clearly seen when a white background such as a handkerchief was held behind it. The cord having been carefully moved till it was intersected by the cross-wires, the scale reading was taken, the telescope lifted out of the Ys, and turned over, and the operation repeated, the mean of several such observations being adopted as the true point on the cliff pedestal.

The line having now been established at three important points,

permanent marks were fixed at the bottoms of the gorges, to serve as bases for carrying on the underground work from the ends of the tunnel. Small pedestals of masonry were constructed in positions where the transit could be used; and the mean result of a number of careful observations having been obtained, the transit-instrument was taken to the pedestals at the bottom, on the opposite side of the river to the mouth of the tunnel.

The line was marked on brass scales, fixed in the rock just over the tunnel mouth, and a fine thread with plummet hung so as just to touch the scale; and the mean of a number of sights being taken, the line through these points from the point on the pedestal, formed a base which was produced into the tunnel.

The first contractor, Mr. Edwards, died on the 5th of May, 1881, at which time he had driven 862 feet of tunnel at the outlet end, and had sunk one shaft to grade. Owing to the river keeping high, the work at the inlet had been suspended some months before, and the open cut in front was all that had been done at that place. Between that time and the reletting of the contract, on the 29th of July, to Messrs. Topham, Angus and Smith, preparations were made for carrying on the alignment from shafts, by the building of pedestals at suitable points along the line. Four of these were erected between Wonson's Hill and the Cataract River, similar to the one already described, but they did not need to be so high. Sets of observations were taken from the main observatories, and the centre line was eventually established at all the intermediate pedestals.

A good time for observing was found to be in fine weather just before sunset; but a calm night was the best of all, the instrument then remained very steady, and when large powerful lamps were used for signalling, the work could be carried on most satisfactorily. The best object, for sighting at long distances at night, was a steel bar of a thickness depending on the length of sight, with a background of calico immediately behind it; if a strong light, from a lamp with good reflector, was now cast upon the back of the screen, the bar showed out clearly and sharply. A magnesium-wire lamp was tried on one occasion for this purpose, but the light was uncertain, difficult to control and very expensive; and, in addition, inside the tunnel its fumes were an annoyance. Night observations on the surface above the tunnel were attended with serious inconvenience from the numerous fires of the miners camped along the line.

The bars for sighting were of steel truly straight, of diameters varying from $\frac{1}{4}$ to 1 inch, and 6 feet in length. All the bars were

capable of being suspended from tripod legs of pine; and they were sharpened to a point at the bottom. Plummets of 10 or 12 lbs. weight, bored through their centres to receive the bars, were attached. At 4 miles the 1-inch bar was always used; at 1 mile the $\frac{1}{4}$-inch bar was sometimes found too thick, and a cord $\frac{1}{8}$ inch in diameter with a plummet was substituted. The bars were painted black, and a screen of calico was placed behind, but in day-work it was necessary to have the background some distance away from the observatory, to allow as much light as possible to enter through the doors.

The new contractors having determined to carry on the tunnelling from shafts, in addition to the two ends, the sinking of three was immediately proceeded with, and subsequently two others were put down; and tunnelling from the shaft sunk by the former contractor was at once commenced.

The ordinary method of transferring the line to the bottoms of the shafts by plumbing was adopted. At the shafts, from which long distances were expected to be driven, pedestals of masonry were erected, one on each side, on the centre line of the tunnel, and about 50 feet apart, the tops being level, and 1 foot above the brace or platform; holes were drilled in them, and brass plates leaded across as previously described. Points on the centre line were then accurately established on each from the nearest observatory. A steel wire, about $\frac{1}{50}$ inch in diameter, was then strained at its utmost tension, as determined by a Salter's spring balance, from pedestal to pedestal, across the shaft, being made fast to posts at the ends, and adjusted to cover the particular division on each scale, which corresponded with the centre line.

A calm morning was essential for this work. The wire having been placed in position on the line, the process of plumbing down the shaft was proceeded with. From the mouth, and up to 600 or 800 feet in, it was sufficient to use silk, or hemp-fishing line, about $\frac{1}{30}$ inch in diameter with an 8-lb. plummet.

As the headings increased in length, copper wire was sometimes used, but was liable to break. Steel piano-wire about $\frac{1}{60}$ inch in diameter proved best, with a 56-lb. plummet of cast-iron truly turned; this wire was suspended from a tripod, placed across the horizontal wire, and standing on the platform of the shaft, through which a hole was cut to allow it to pass; the tripod was provided with an apparatus, by which the plummet could be raised or lowered to its proper position, and, by screw adjustments, the pendent wire could be brought just to touch the horizontal wire strained across the pedestals.

An assistant at the bottom of the shaft placed the plummet in a vessel containing water, and gave the necessary directions through a speaking-tube to the observer on top, to cause the wire to almost touch a brass scale screwed on to a beam of timber, fixed into the rock over the crown of the tunnel. In about half-an-hour the heavy plummet became steady, and the reading on the scale was noted. As it was desirable to obtain the longest base possible in the shaft, the plummets were hung as close as possible to the sides without touching anywhere. After the wire had been brought into position, and before the scale reading was taken, it was carefully examined from top to bottom with a candle, the observer going down very slowly in the cage. After this no one but the observer was allowed on the platform, and the pumping, blowing, and hoisting engines were stopped; even the observer himself did not move from the position selected for noting the coincidence of the vertical and horizontal wires, as the least movement about the platform caused vibration in the vertical wire. The horizontal wire during the interval was watched, to see that it did not shift off the marks. The centre point on each scale at the bottom of a shaft having been thus established, the heavy plummet was removed, and the steel wire drawn up; fine cotton or silk threads were then substituted, with plummets of sufficient weight in water, suspended from the scales, and adjusted to the marks. An 8-inch transit theodolite on its centering legs was then set up a short distance from the plummets, in one of the headings, and the intersection of its cross wires brought into coincidence with the line as given by them. The striding level was always used during the operation, to adjust the horizontality of the axis, and the focussing screw was always turned the same way, and never reversed; when these precautions were taken, and with a little practice, very accurate results were obtained. After the instrument had been adjusted to prolong the line into the heading, a hole was drilled in the roof some distance in, and a wooden plug inserted; the point was then obtained on this plug, by sighting on to a plummet lamp suspended from it, and the mean of several observations, reversing each time, was taken as a true point in the line. Horse-shoe nails hammered flat at the top, with a small hole bored through, were found best to suspend the plummet lamp from, as the metal bends readily when tapped on one side or the other without breaking. When the headings were driven over 1,000 feet, the plummet lamp was suspended by a string from a brass scale, in a beam of timber fixed in the crown of the tunnel. For signalling, large railway semaphore lamps were used, showing red, green and

white lights; when the tunnel was clear of smoke, these were visible about 2,000 feet away.

As no marks in the shafts or tunnel could be depended on to remain for any length of time without shifting, repetition in these, as in all other cases in tunnel alignment, was invariably relied on to eliminate error, and no single set of observations was trusted for driving the tunnel any considerable distance. Before the headings were driven 1,500 feet from a shaft, the whole operation of transferring the alignment below into the tunnel was repeated, independently of any previous work; even the points on the scales of the pedestals at the top of the shaft were checked with the transit from the nearest observatory.

The levels in the tunnel were given in the following manner:— The value of a bench-mark at the bottom of a shaft having been ascertained, by measuring the calculated distance with a steel tape from the surface, the levels were run into the headings, and at intervals of 100 feet, hooks in pegs in the sides of the tunnel, and opposite to each other at right-angles to the line, were so adjusted that strings passed through them and hauled tight, were exactly 2 feet 9 inches above the grade.

The plummet lamps, hanging from the centre pegs in the roof, being then lowered till their lights were even with the horizontal strings, the axis of the tunnel was determined, and the miners were provided with both line and grade; all they required to do was to place a candle at the face in line with the lights from the plummet lamps, and measure down 2 feet 9 inches, to find the grade of the invert. Bench-marks were established at intervals of 400 or 500 feet, and were frequently checked.

The plummet lamps were manufactured after the design of an American mining engineer, Mr. Eckley B. Cox; they were of brass, shaped like an ordinary plummet, and were hollow to contain oil; they swung in gimbal rings, suspended by chains from a hook, consequently the point of suspension and the centre of the lamp-flame were always truly vertical. These lamps were found indispensable where great accuracy was required, and the flame, though only about $\frac{1}{2}$ inch high, and about $\frac{1}{4}$ inch in diameter, could be seen distinctly through the telescope at very long distances when the headings were clear.

The lengths of the headings, and the results of the alignment when the junctions were effected, are given in the following Table:—

Name of Heading.	Length in Feet.	Date of Commencement.	Date when Headings met.	Error	
				In Line in Inches.	In Grade in Inches.
Inlet	2,054·0	June 10, 1881	Aug. 16, 1884	3	$\frac{9}{16}$
No. 5 West	1,513·25	Feb. 23, 1883			
No. 5 East	935·0	„ 23, 1883	Jan. 25, 1884	3	No error
No. 4 West	1,970·0	Jan. 13, 1882			
No. 4 East	2,468·0	„ 13, 1882	June 28, 1884	$\frac{3}{8}$	$\frac{1}{16}$
"A" West	425·0	Jan. 26, 1884			
"A" East	496·0	„ 26, 1884	Aug. 11, 1884	$\frac{3}{8}$	$\frac{1}{8}$
No. 3 West	1,359·0	Jan. 29, 1883			
No. 3 East	1,323·42	„ 29, 1883	July 28, 1884	$\frac{5}{8}$	$\frac{1}{4}$
No. 2 West	3,018·0	Nov. 18, 1881			
No. 2 East	2,385·0	„ 25, 1881	Aug. 11, 1884	$\frac{3}{8}$	$\frac{1}{4}$
No. 1 West	2,286·0	Sept. 5, 1881			
No. 1 East	1,126·58	„ 5, 1881	Sept. 23, 1882	$2\frac{3}{4}$	$\frac{1}{16}$
Outlet	2,148·0	Feb. 9, 1880			

The first junction occurred when the headings from the outlet and No. 1 shaft met.

The base of 3,274 feet from the mouth to the shaft was then produced into the west heading; this was the only case where advantage was taken of a junction to obtain a longer base. In every other instance the alignment depended entirely on the production of the 12-foot shaft bases.

After the tunnel had been pierced through, cleaned, and all timber removed, daylight at one end was distinctly seen without the aid of a telescope from the other, $4\frac{1}{2}$ miles away.

The Author desires to avail himself of this opportunity, to express his thanks to the Engineer-in-chief, Mr. E. O. Moriarty, M. Inst. C.E., who from the first took a lively interest in the work, and whenever difficulties presented themselves gave his valuable advice; also to Mr. Harold Arthur Blomfield, Stud. Inst. C.E., to whom the success of the alignment was in a great measure due.

The Paper is illustrated by a diagram of the longitudinal and the cross section of the tunnel, from which the Figs. in the text have been reduced.

(*Paper No. 2265.*)

"Improved Systems of Chaining for Land and Engineering Surveys."

By William Mann Thompson, M.A., B.E., Assoc. M. Inst. C.E.

Of these improved methods of measurement the first described is that which, after many trials and experiments, has been found to give results which approach almost to the accuracy of trigonometrical measurement, and is a system which has been proved most suitable for the detail work of the City of Sydney. This particular use of 1-chain lengths is the most convenient for working in the heavy traffic of a crowded city.

The second system described is superseding all other modes of measurement in suburban and country districts—where the lines are long and there is little or no traffic to interfere with the use of long lengths of steel bands.

Of these two systems the first has had its origin from the necessity that existed of having some good, quick and reliable method for measuring traverse and working lines in carrying out the detail trigonometrical and sewerage-survey of Sydney. This survey, which has been carried out in a somewhat similar manner to that of the English ordnance survey, was started on the recommendation of the late Mr. W. Clark, M. Inst. C.E., that good and trustworthy detail plans of the city should be prepared, to enable the final works for the disposal of the sewage to be properly designed and constructed.

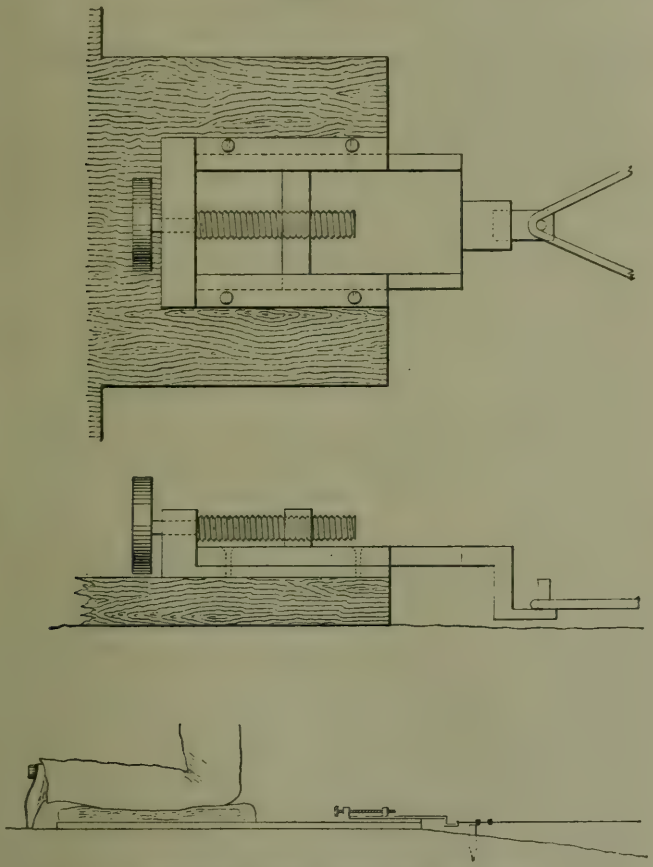
As is well known, in surveys for such purposes as Metropolitan railways, sewerage, &c., where all details in the shape of buildings, existing lines of drains, watercourses, and property boundaries require to be shown with great accuracy, and where in consequence a great number of traverse lines must be laid out and chained, it is essentially necessary that some method should be adopted for the measurement of these lines which will give accurate results, and at the same time be expeditious.

In this particular case, where the work as it proceeded was connected with the main trigonometrical stations, and the co-ordinate values of the detail stations were checked by comparison with those of the main survey, it was found that the old system of

chain surveying was most unsatisfactory, and consequently it was abandoned.

The first improvement adopted was the use of a steel riband about $\frac{1}{2}$ inch to $\frac{3}{4}$ inch in breadth, and about $\frac{1}{32}$ inch in thickness. This riband was used in a similar manner to the old chain, that

FIGS. 1.



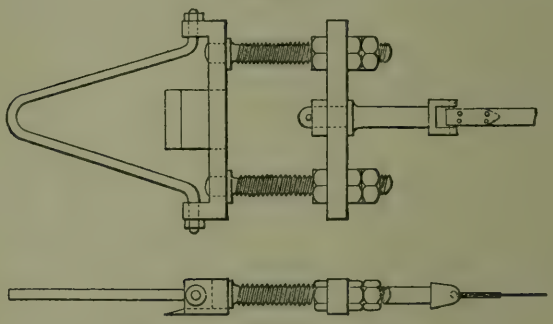
ADJUSTING SLIDE; BACK END OF CHAIN.

is, with the ordinary chain arrows and plumbing arrow, and no allowance was made for sag or for alteration in length arising from differences of temperature; consequently the results obtained, as compared with the calculated results, were not as good as they might have been. As an improvement on this, a steel riband $\frac{1}{8}$ inch wide and $\frac{1}{64}$ inch thick was substituted, and this riband

was furnished with adjustable handles worked by means of screws and lock-nuts, so that it was capable of being adjusted to the standard laid down at Sydney Observatory.

The results with this second riband were much superior to any obtained previously, but there was still room for improvement, and to effect this improvement was now what remained to be done. In the first place the holding of the back end of the chain by the hand was found to be a source of error, and to obviate this a contrivance was designed so that when the strain was applied the whole weight of the back chainman should be available to resist it. This contrivance (Figs. 1) consisted of a board about 1 foot 6 inches long by 14 inches broad, on which was nailed a leathern pad to act as a cushion for the man's knees; to the front of the board was attached a brass slide worked by a large milled-headed

FIGS. 2.

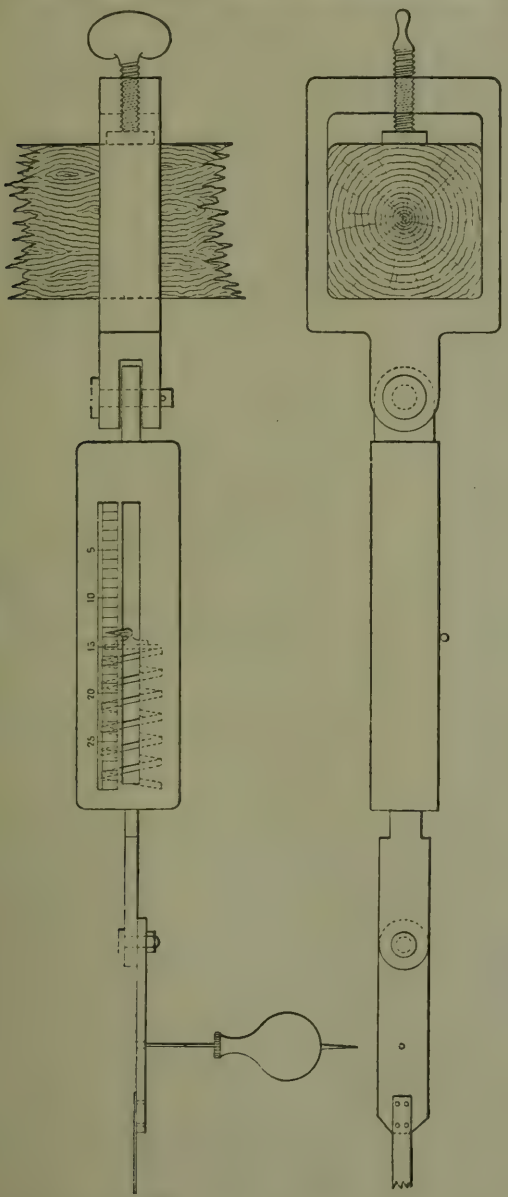


CHAIN-HANDLE FOLLOWING END.

screw, and capable of a forward and backward movement; the front end of this slide terminated in a hook, to which the chain was fastened, the end of the chain having a special handle with a loop attachment, into which the hook worked; the handle was also furnished with a small steel knife-edge (Figs. 1 and 2).

Again it was found that unless the men maintained a uniform strain on the riband error was caused by the different tensions applied. To obviate this, on the leading end of the riband a small spring-balance (capable of registering a pull of 30 lbs.) was placed, and this balance was attached to a collar which could be moved up and down a bar (called a straining-bar), and by means of a butterfly-screw clamped in any desired position (Figs. 3). To the other, or hook end of the balance, was attached a brass plate furnished at one extremity with a swivel attachment for connecting the riband, while the other extremity was connected with the

balance. In the centre of this plate was drilled a hole $\frac{1}{32}$ inch



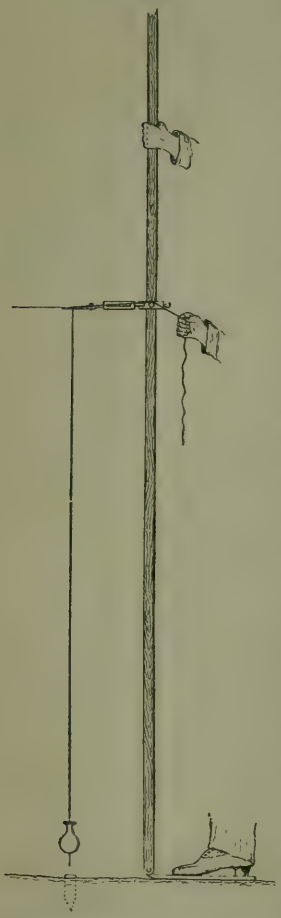
FIGS. 3.

LEADING END OF CHAIN, SHOWING CONNECTION TO SPRING-BALANCE AND STRAINING-BAR.

in diameter, to allow the string of a plumb-bob to pass through,

and the distance from the centre of this hole to the edge of the knife-edge on the back end of the chain was accurately adjusted to the observatory standard. This adjustment being made with the riband, supported at its extremities only, and strained with the same tension that is intended to be applied as a working strain, which is generally about 16 lbs., any error from sag is thus eliminated.

Fig. 4.



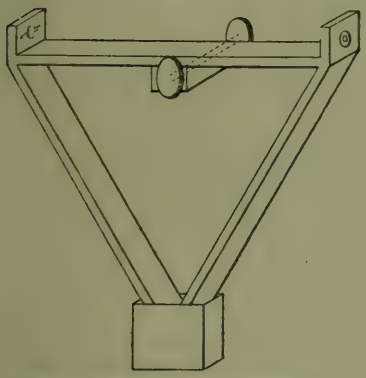
Straining-bar, Leading End.

The straining-bar, a piece of hard wood $1\frac{1}{4}$ inch by $1\frac{1}{4}$ inch, and from 12 to 14 feet long, is furnished at its foot with an iron shoe large enough for a man to put his foot upon to steady the bar, while with his hands he pulls the bar as a lever turning upon a hinge in the shoe as a fulcrum (Fig. 4). At the outset, when the riband is adjusted, the temperature is carefully noted by a delicate thermometer attached to it, so that the bulb may be in contact with the steel, care being taken to keep the whole length of riband in shade during adjustment. The reading of the thermometer is used afterwards as a standard by which all lengths made in future measurements are corrected for expansion or contraction of the metal.

The chaining with this contrivance is carried out as follows, and for example it is assumed that the accurate distance between two points A and B is required, and that A is on the summit of a hill, while B is at a lower level. Here it is necessary to state that in using this method of chaining it is always usual to work with the leading or straining-bar end on the downhill side, the reason being obvious; but in case a hill intervenes between the extreme ends of the line, then a point should be lined in upon its summit, and this used as a starting point working both ways and taking the sum. All attachments having been made, the man at the back end kneels on the pad, and with the screw brings the knife-edge exactly over the starting point; the person in charge

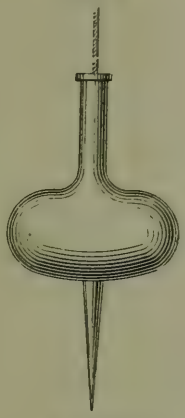
then sights the back end of the chain with a small self-adjusting plumb-level (Fig. 5), and gives the leading man the height to which he must slip the collar on the straining-bar. This fixed (and the temperature from the attached thermometer noted), the leading man puts his foot upon the shoe, and pulls the bar until 16 lbs. is registered on the balance, then, holding the bar with one hand, with the other he raises or lowers the plumb-bob until it just swings clear. An assistant now notes the approximate position of the point of the plumb-bob, and drives into the ground either a small wooden peg about 1 inch by 1 inch, or else a clout-headed nail, according to the nature of the soil (if rock, a scratch is made); a piece of gummed paper is then affixed to the nail or peg,

FIG. 5.



SELF-ADJUSTING CHAIN LEVEL.

FIG. 6.



PLUMB-BOB.

on which, when the plumb-bob is allowed to swing again, the point directly under its centre is marked. A special plumb-bob with a low centre of gravity, and a long, fine steel point, is used for this purpose (Fig. 6).

Lately it has been found better to dispense with the plumb-bob swinging from the riband to the ground, on account of the error caused by currents of air, and to use instead a small plumb-bob hung about $\frac{1}{2}$ inch from the plate (Fig. 3). After setting a light theodolite up as near as possible at right-angles to the end of the chain to sight the string where it passes through the plate, the telescope is depressed and a sharp pointed pencil held vertically on the peg is put in line, which when in correct position is twisted, making a small dot sufficiently distinct for the back chainman to see. The chain is now carried onward and the process repeated for

the second chain. To facilitate the setting of the theodolite at right-angles to the chain, close to the spring balance, a light wooden bar is placed and clamped so as to lie at right-angles to the riband. By keeping the extreme ends of this bar in line (or in short seeing straight along it) the position in which to set up the instrument is given with tolerable accuracy.

The whole operation, though seeming somewhat complicated and tedious, after a little practice is quickly and easily done, and gives such excellent results (Appendix, Tables I and II, Traverses "A" and "B") that there is never any necessity for checking by re-measurement.

The average rate of progression on undulating ground is from 20 to 25 chains per hour, and this is usually performed with two men, an assistant and a boy, besides the officer in charge—the assistant to mark the chain-lengths, pick up chainage of any intermediate station and take the temperature readings, a man at either end to work the chain, and the boy to carry forward any ranging-rods required to mark the line; and lastly the officer in charge to work the theodolite and note results, which are generally tabulated thus :—

Line.	Temperature Fahrenheit.	As Chained Links.	Correction.	Corrected Chainage Links.	Remarks.
A to B	{ 82° 94° }	1,421,64	+0·16	1,421·80	..

The theodolite need not be larger than a 4-inch instrument, care of course being taken that the levelling adjustments are perfect, as also the adjustment for the horizontal axis.

For all practical purposes in a chain length of riband, the expansion of steel is 0·01 inch for a rise of 2° Fahrenheit, and taking 0·08 inch as approximately equal to 0·01 link the correction for temperature is easily and quickly applied. Thus in the above example the riband used was standard at 70° Fahrenheit, consequently the correction for expansion will be—

$$\frac{82° + 94°}{2} = 88° \text{ mean temperature.}$$

$$88° - 70° = 18° \text{ excess above standard.}$$

$$\frac{18°}{2} = 0·09 \text{ inch for 1 chain.}$$

$$0·09 \times 14 = 1·26 \text{ inch for 14 chains.}$$

$$\frac{1·26}{8} = 0·16 \text{ (nearly) link.}$$

And this must be added to the measured chainage, seeing that since the chain is long the chainage must consequently be short.

The mean temperature is used for the final correction and with this (temperature) correction it is found that the errors occur, as frequently the line is partly in shade and partly in sun, and, owing to the bad conducting property of the glass bulb of the thermometer, the steel riband alters in length faster than the attached thermometer records or registers the variations of temperature. This, however, might be partly remedied by coating the bulb of the thermometer with some dark adhesive substance, which would have the effect of rendering it more sensitive. As an example of the accuracy of measurement obtained by this method two closed traverses are given in the Appendix.

In each of these the angles were taken with a Troughton and Simms 6-inch transit theodolite, each angle being repeated four times, and at each reading the mean of the verniers was taken, and finally the mean of the readings. In both cases the difference of the included angles from an exact multiple of 90° did not exceed 14″. In both cases ("A" and "B") the lines were chained on the system before described; but in the first traverse, "A" (Table I), the marking was done with the plumb-bob swinging full length. In the second traverse, "B" (Table II), the marking was done with a theodolite.

As another example of the accuracy obtained by this method of chaining, the following problem was worked out in the presence of ten or twelve persons interested in accurate measurement; and it was done to show that in the event of stations being lost or destroyed their position could be without much difficulty again defined. A stake (centred with a tack) was driven in the ground in such a position that three trigonometrical stations (in this case spires of churches) were distinctly visible from it; and also a station of the detail survey (which for the purpose of this experiment was supposed to have been lost) was not only visible but accessible for direct measurement. By observing the three spires from the stake the old well known three-point question was worked out, and the co-ordinate values of the stake were determined; then, from these values and the values of the detail station, which were known, the direct bearing and distance from the stake to this station were calculated. Finally the direct distance was measured and compared with the calculated distance; the results being:—

	Bearing. ° ′ ″	Links.
By calculation	342 22 26	183·68
By measurement	342 22 2	183·75

This three-point problem was then again performed from a second point, the results in this case being :—

	Bearing. ° ′ ″	Links.
By calculation	218 57 22	375·41
By measurement	218 57 27	375·49

This method of the straining-bar will be found of great service to those who wish to lay out lines for such purposes as bases from which to triangulate a river for a bridge, and where the more elaborate and costly rods as used on a base survey are not obtainable; and still more so for such surveys as have already been mentioned, viz., those for metropolitan railway- and sewerage-works, and, if required, could, with a slight modification, be used with advantage for setting out railway or other curves. The few drawings attached show all the necessary arrangements, which are usually made as simple and as light as possible.

The second system of long-wire chaining is, as has already been mentioned, more suitable for working in the open country. The system had its origin in New South Wales, and is not, the Author believes, used in any other part of the world.

This long wire can be applied for measuring in either of three different ways :—I. Using a long wire with a constant tension and supporting it at short intervals. II. Using a long wire with a constant tension, supported only at its extremities, then correcting for sag. III. Using a long wire supported only at its extremities, but varying the tension according to length.

For either of these cases it is customary to use a long light steel riband, the ordinary size of which is $\frac{3}{40}$ inch broad, of a weight of about 1 lb. to a length of 350 links. This wire may be made in one length of 5 or 10 chains, or else made in 1-chain lengths so that each length may be unshackled. This latter method of being able to lengthen or shorten the riband is found the most convenient, as for all ordinary purposes chaining 5 chains at a time gives the best results and involves less calculation for corrections.

These ribands are generally constructed by the owners, who buy a roll of the material and cut it to suit themselves. The most common method, as before stated, is to cut it into lengths and then bend the ends into loops, similar to Fig. 7, the distance between the inner side of the loop at either end being made equal to 1 chain. The doubled-over ends are prevented from bending back by a slip made of a piece of sheet brass bent round so as to form a socket —proper shackles are now made and sold ; but in practice, where it sometimes happens that a length will get twisted and broken, and

appliances are not always to hand to remedy the defect and adjust new ends, it is more convenient to use the loop connections, which

FIG. 7.

LOOP CONNECTION.

are quickly and easily made, and do not require drilling, &c. In using these ribands in the field, instead of measuring horizontally as in the previous method and in all old systems, all lengths are measured on the hypotenusal system, that is, the angle of elevation or depression, as the case may be, is taken with a theodolite, and the measurement is made from the horizontal axis of the instrument to the point observed (Fig. 8), the horizontal length being afterwards deduced by calculation, results being kept in a book specially prepared and tabulated somewhat in this manner:—

Line.	Portion.	Angle E or D.	Temperature Fahrenheit.	Length as Measured.	Length Corrected for Temperature.	Horizontal Length.
A to B	A to 1					
	1 to 2					
	2 to B					

With regard to the relative merits of the three different methods of using the wire, some prefer one, some another, and, if properly worked, there is little to choose between them; II and III are most suitable for rough and broken country; I involves less calculation but requires more men for effectual working.

In working method I, namely supporting a long wire at short intervals and using a constant tension, it is necessary for roads, streets and stony ground, to use light rods supported in a vertical position, either by means of tripods or else fitted with blocks (Figs. 9), these rods having an arm capable of being moved up and down them, and clamped at any desired height. For open country, paddocks and grass lands, where a shod pole can be struck upright in the ground, ordinary ranging rods fitted with the arm suffice. Then, as soon as the elevation or depression of the chord has been observed and noted, and before the instrument is unclamped, these rods are lined in, generally about 1 chain apart, and the slipping arm is moved up or down and adjusted to the line of collimation of

the horizontal wire and there clamped; the riband is now supported on these arms, the tension applied, and the measurement made, as before stated, to the horizontal axis of the instrument. In these measurements, as it is very unlikely that they will all be in even chains, the fractions of a chain are taken by means of a Chesterman's steel box-tape divided to hundredths of a link. The end of this tape is generally attached to the loop of the chain length, ending nearest to the instrument. Thus, suppose the line to be 4 chains and a fraction, the tape would be attached to the end of the fourth chain, the spring balance to the end of the fifth chain; the riband would be pulled taut past the theodolite, and the officer in charge would manipulate the tape and read the distance.

Fig. 8.

Long-wire Chaining.

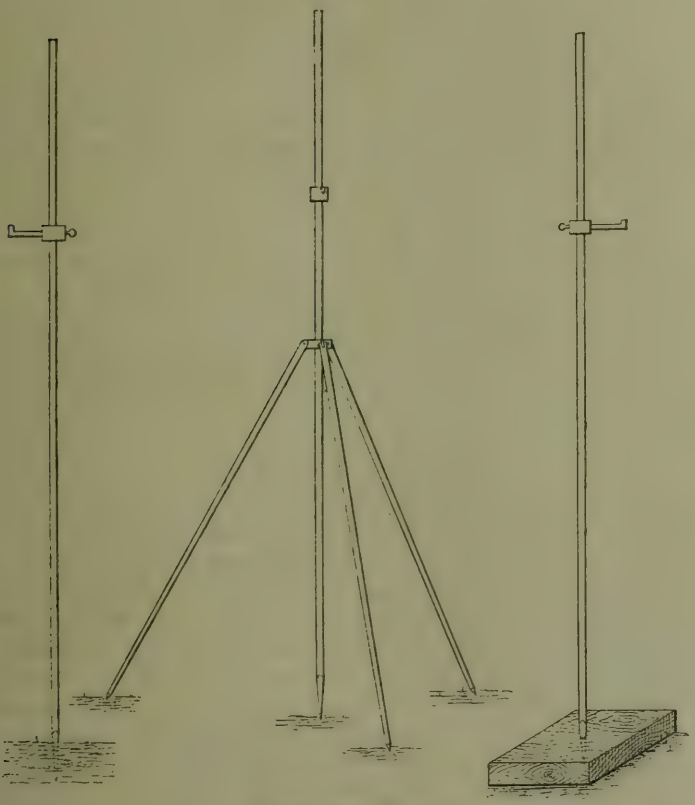
This system of supporting the riband at chain intervals, for all practical purposes does away with the correction for sag, as the difference between the chord and the arc for a chain length of light riband when a tolerable tension is applied, is practically nothing.

The disadvantage of the method is the time consumed in lining in and adjusting the rods, and the extra paraphernalia in the form of supports required to be carried about. The only necessary corrections, however, are those for temperature and reduction to the horizontal.

Method II.—Supporting a long wire at its extremities only, and using a constant tension.—This, as will be readily seen, requires a correction for the curved form of the riband, or, as it is here termed, "a correction for sag;" and this correction will vary according to the length of riband.

Now it is found in practice undesirable to use a riband more than 5 chains in length, or to apply a tension much greater than 9 or 10 lbs. For with this length of riband and this tension the tension at the centre will differ very little from the applied tension, and certainly not sufficient to cause any serious error; whereas if a longer length is used the tension at the centre must be calculated.

FIGS. 9.



SUPPORTING RODS.

Again, as regards the adoption of a pull of 9 or 10 lbs., unless shackles are used, or the riband is in one very long length, any great increase in this amount would cause elongation from the loop connections drawing.

In making the calculations for the difference in length between the chord and curve of the wire as long as the extremities are fairly

on a level, or the elevation of one does not exceed that of the other by more than about 14° or 15°, the ordinary formula for a catenary curve is applicable :—

By $$\frac{a}{2}\left\{e^{\frac{b}{a}} - e^{-\frac{b}{a}}\right\} = c.$$

Where e = base of Napierian logarithms.
a = length of wire equal in weight to the tension at the lowest point of the curve.
b = half distance between the ends.
c = half length of the curve.

When, however, the riband is longer than 5 chains, the tension at the centre will require to be calculated, and this may be found from—

$$T^2 = H^2 + P^2$$
$$H^2 = T^2 - P^2$$

Where T = applied tension, or tension at the ends.
H = horizontal tension at centre.
and P = vertical load or weight of half the wire (in this case where 350 links of wire weigh 1 lb.) = $\frac{b}{350}$, so that the above equation becomes :—

$$H = \sqrt{\left\{T^2 - \left(\frac{b}{350}\right)^2\right\}}.$$

The following Table will give the correction for sag, the first four lines from 2 chains to 5 chains being calculated on the assumption that the tension at the centre is equal to the applied tension, and the last 5 chains, from 6 chains to 10 chains, calculated with the tension—as given by the above formula and calculated below :—

Corrections for Sag.				Tensions at Centre.				Corrections for Sag.		
Chains.	8 lbs.	9 lbs.	10 lbs.	Chains.	8 lbs.	9 lbs.	10 lbs.	8 lbs.	9 lbs.	10 lbs.
								Links.	Links.	Links.
2	0·032	0·020	0·020	6	7·954	8·959	9·963	1·188	0·951	0·742
3	0·132	0·114	0·090	7	7·937	8·944	9·949	1·814	1·521	1·132
4	0·344	0·270	0·226	8	7·918	8·927	9·934	2·778	2·190	1·774
5	0·680	0·536	0·430	9	7·896	8·908	9·917	3·976	3·118	2·496
..	..	..	..	10	7·871	8·885	9·898	5·500	4·288	3·464

As an example: suppose it be required to know the length of wire between two points 4 chains distant and on about the same level. Also let 350 links in lengths of wire = 1 lb., and suppose the tension at the ends to be 9 lbs.

Here $a = 350 \times 9 = 3{,}150$

$$\frac{a}{2} = \frac{3{,}150}{2} = 1{,}575$$

$$\frac{b}{a} = \frac{200}{3{,}150} = 0{\cdot}063492$$

log. 200 $2{\cdot}3010300$
log. 3,150 $3{\cdot}4983106$
$\overline{2}{\cdot}8027194$

$$e^{\frac{b}{a}} = 2{\cdot}7 \text{ \&c.}^{0{\cdot}063492}$$
$$= \log. 2{\cdot}7 \text{ \&c.} \times 0{\cdot}063492$$
$$= 0{\cdot}4342945 \times 0{\cdot}063492$$
$$= 0{\cdot}0275742$$

number corresponding $= 1{\cdot}06555$

$$e^{-\frac{b}{a}} = \frac{1}{e^{\frac{b}{a}}} = \frac{1}{1{\cdot}06555}$$
$$= 0{\cdot}93848$$

$$e^{\frac{b}{a}} - e^{-\frac{b}{a}} = 1{\cdot}06555 - 0{\cdot}93848$$
$$= 0{\cdot}12707$$

$$\left(e^{\frac{b}{a}} - e^{-\frac{b}{a}}\right)\frac{a}{2} = 0{\cdot}12707 \times 1{,}575$$

$\overline{1}{\cdot}1040430$
$3{\cdot}1972860$
$2{\cdot}3013236$ log. of $200{\cdot}135$

$$= 200{\cdot}135$$
$$= c$$

Then $200{\cdot}135 \times 2$
$= 400{\cdot}270$
= length of riband in curve.

That is, the length of curve is longer than the chord by 0·27 link, so that to measure 4 chains with this wire and with a tension of 9 lbs. the wire would have to be made 400·27 links long. Now if it is decided to apply always the same tension it will readily be seen that, by calculating the difference of chord and arc for each

increase of 1 chain, the ribands, when being adjusted can be marked if in one piece, or the lengths can be so arranged that, when unsupported, the marks or ends of lengths will denote even chains on the chord; thus:—

The first length with a tension of 9 lbs. might be made .	100·000
The second	100·020
The third	100·094
The fourth	100·156
The fifth	100·266
	500·536

And this marking will give approximately accurate results as long as the angle of elevation or depression does not exceed 15°. For greater elevations or depressions it would be necessary to calculate the correction which would diminish as the angle increased, supposing the tension applied at the higher end.

If it is required in this system of constant tension to correct for sag when the angle of depression or elevation of the chord is considerable, the corrections necessary may be found from the following formulas[1]:—

Let r = correction required.
t = constant tension.
l = length.
w = weight per chain.
θ = angle between chord and zenith.

Then $r = \frac{l^3 w^2}{24 t^2}$ when $\theta = 90°$, and when θ differs from 90°.

$$r = \frac{l^3 w^2 \sin^2 \theta}{24\left(t + \frac{l w \cos \theta}{2}\right)^2}.$$ If tension is applied at the lower end of the riband.

$$r = \frac{l^3 w^2 \sin^2 \theta}{24\left(-\frac{l w \cos \theta}{2}\right)^2}.$$ If tension is applied at the upper end of the riband.

[1] For the equations involved in this method for calculating the correction for sag, when the angle of chord is considerable, and also for those made use of in the third method of variable tensions, the Author is indebted to a brother officer, Mr. G. H. Knibbs, who has made this his special study, both practically and theoretically, and with whose kind permission the equations and Tables following are inserted.

If r' is taken to represent the corrections reduced to their horizontal value, these last two equations become—

$$r' = \frac{l^3 w^2 \sin^3 \theta}{24\left(t + \frac{l w \cos \theta}{2}\right)^2}.$$

$$r' = \frac{l^3 w^2 \sin^3 \theta}{24\left(t - \frac{l w \cos \theta}{2}\right)^2}$$

Method III.—With regard to the third method, using a long wire, supported only at its extremities, but varying the tension according to the length, all that need be done is to note the number of chains of wire between the instrument and the fixed point, and then to turn to a Table, which for convenience is kept pasted in the field-book, and obtain from this the required tension for the length out, and see that this tension is the one applied.

These Tables are usually calculated by the officer himself for whatever description of wire he may consider suitable to use, and they may be readily compiled from Table III.

The equations necessary for the calculations may be thus briefly stated :—

First. When the ends of the suspended riband are in the same horizontal plane.

Let h = tension at lowest point in curved riband.
t = standard tension.
w = weight of 1 chain of riband.
k = 0·00000779 chain; this is a constant deduced by experiment, and represents the extension produced by a tension of 1 lb. in a 1-chain riband weighing 1 lb.

Then $$h^3 - th^2 - \frac{l^2 w^3}{24 k} = 0;$$

from which h may be easily found from a Table of cubes and squares, and this is the tension to be applied at either end of the riband.

When the ends of the riband are not in the same horizontal plane :—

Let θ = angle between chord of riband and zenith.
T' = tension to be applied at upper end.
T = tension to be applied at lower end.

$$\tau = \frac{T' + T}{2}.$$

$$\tau^3 - t\,\tau^2 - \frac{l^2\,w^3 \sin^2\theta}{24\,k} = 0, \text{ from which } \tau \text{ is found.}^1$$

Then $$T' = \tau + \frac{l\,w\cos\theta}{2}.$$

$$T = \tau - \frac{l\,w\cos\theta}{2}.$$

If the values for h (*i.e.*, tension at lowest point in curved riband) have been computed for the various lengths of riband used, then T' and T may be found approximately by the equation :—

$$T' = t + (h - t)\sin\theta + \frac{l\,w\cos\theta}{2}.$$

$$T = t - (h - t)\sin\theta - \frac{l\,w\cos\theta}{2}$$

These equations are empirical, but give sufficiently accurate results for values of θ between 60° and 90°, angles which occur most frequently in practice.

The Paper is accompanied by several diagrams, from which the Figs. in the text have been engraved.

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[1] For values of τ in this equation, see Table IV.

APPENDIX.

TABLE I.—TRAVERSE "A."

Line.	Bearing.	Distance.	North.	South.	East.	West.
	° ′ ″					
1 to 2	209 29 44	427·37	..	371·98	..	210·42
2 „ 3	167 46 36	1,403·68	..	1,371·86	297·19	..
3 „ 4	79 27 47	659·47	120·60	..	648·35	..
4 „ 5	79 15 37	506·92	94·46	..	498·04	..
5 „ 6	83 37 40	671·56	74·53	..	667·41	..
6 „ 7	324 42 10	421·70	344·18	..	..	243·66
7 „ 8	336 48 30	334·16	307·16	..	..	131·59
8 „ 9	45 20 59	958·60	673·68	..	681·96	..
9 „ 10	339 10 48	889·77	831·67	..	..	316·25
10 „ 11	336 0 53	842·42	769·67	..	..	342·45
11 „ 12	325 43 21	406·38	335·80	..	..	228·88
12 „ 13	329 16 48	508·02	436·73	..	..	259·52
13 „ 14	292 57 7	535·35	208·76	..	..	492·97
14 „ 15	257 31 25	499·16	..	107·84	..	487·37
15 „ 16	310 50 34	489·63	320·21	..	..	370·41
16 „ 17	168 40 2	1,097·86	..	1,076·45	215·74	..
17 „ 18	164 56 53	731·52	..	706·42	189·97	..
18 „ 1	187 25 24	890·47	..	882·94	..	115·03
			4,517·45	4,517·49	3,198·66	3,198·55

Length of traverse, 1 mile 42 chains 74·04 links.

TABLE II.—TRAVERSE "B."

Line.	Bearing.	Distance.	North.	South.	East.	West.
	° ′ ″					
1 „ 2	326 53 46	954·98	799·970	..	..	521·571
2 „ 3	315 38 26	816·56	583·814	..	..	570·904
3 „ 4	235 29 43	1,026·80	..	581·656	..	846·165
4 „ 5	327 9 26	628·59	528·118	..	..	340·907
5 „ 6	354 53 35	536·44	534·310	..	..	47·751
6 „ 7	325 29 13	515·24	424·556	..	..	291·932
7 „ 8	232 23 51	919·90	..	561·304	..	728·803
8 „ 9	230 44 43	745·68	..	471·843	..	577·410
9 „ 10	234 48 18	773·17	..	445·625	..	631·831
10 „ 11	230 21 51	691·55	..	441·144	..	532·573
11 „ 12	238 41 2	775·77	..	403·214	..	662·752
12 „ 13	233 32 40	245·57	..	145·918	..	197·517
13 „ 14	146 39 4	2,416·43	..	2,018·537	1,328·400	..
14 „ 15	145 58 5	769·24	..	637·489	430·509	..
15 „ 16	55 51 40	984·80	552·670	..	815·099	..
16 „ 17	57 5 6	1,067·37	580·003	..	896·033	..
17 „ 18	56 44 14	426·62	233·993	..	356·724	..
18 „ 19	54 52 6	1,911·80	1,100·160	..	1,563·531	..
19 „ 1	56 35 57	670·61	369·166	..	559·852	..
		16,877·12	5,706·760	5,706·730	5,950·148	5,950·116

Length of traverse, 2 miles 8 chains 77·12 links.

TABLE III.—TENSIONS to be APPLIED to a WIRE RIBAND WEIGHING 1 lb. PER CHAIN and STANDARD LENGTH at a TENSION of 33⅓ lbs. By Mr. G. H. KNIBBS.

Length Suspended.	Angle of Chord of Riband from Horizontal Line.											
	+ 0° −	+ 10° −		+ 20° −		+ 30° −		+ 40° −		+ 50° −		+ 60° −	
Chains.													
1	37·20	37·19	37·02	37·01	36·67	36·62	36·12	36·10	35·46	35·51	34·74	34·89	34·03
2	44·26	44·21	43·87	43·72	43·03	42·80	41·80	41·50	40·21	39·88	38·35	38·07	36·33
3	51·49	51·43	50·91	50·71	49·69	49·36	47·86	47·40	45·47	44·88	42·58	41·93	39·33
4	58·41	58·35	57·66	57·46	56·09	55·75	53·75	53·23	50·66	49·95	46·89	45·99	42·52
5	64·99	64·94	64·07	63·90	62·19	61·87	59·37	58·87	55·67	54·92	51·09	50·07	45·73
6	71·26	71·22	70·18	70·05	68·00	67·74	64·74	64·30	60·45	59·74	55·15	54·09	48·89
7	77·25	77·23	76·02	75·95	73·55	73·39	69·89	69·65	65·15	64·42	59·06	58·03	51·97
8	83·01	83·02	81·63	81·63	78·89	78·83	74·83	74·61	69·47	68·97	62·84	61·88	54·95
9	88·56	88·60	87·04	87·11	84·04	84·09	79·59	79·52	73·74	73·38	66·49	65·64	57·85
10	93·99	94·00	92·27	92·43	89·01	89·20	84·20	84·29	77·86	77·68	70·02	69·32	60·66

The standard tensions and the tensions for the different lengths suspended for riband of any other *weight* may be found by proportion, or by multiplying the quantities in this Table by the weight of *1 chain* of the riband (used) expressed as a *fraction of a pound*.

TABLE IV.—VALUES for τ in the EQUATION. By Mr. G. H. KNIBBS.

$$\tau^3 - t\,\tau^2 - \frac{l^2\, w^3 \sin^2\theta}{24\,k} = 0.$$

$w = 1$ lb.
$k = 0{\cdot}00000779$ chain.
$l = 1$, 5 and 10.
$\theta = 90°$ and 60°.

Altitude 0°.	$t = 20.$	$t = 25.$	$t = 30.$	$t = 35.$	$t = 40.$	$t = 45.$
Chains.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
1	27·22	30·68	34·50	38·59	42·91	47·38
5	58·75	60·97	63·34	65·84	68·50	71·30
10	88·42	90·42	92·51	94·67	96·93	99·27

Altitude 30°.	$t = 20.$	$t = 25.$	$t = 30.$	$t = 35.$	$t = 40.$	$t = 45.$
Chains.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
1	26·27	29·59	33·56	37·81	42·24	46·83
5	54·18	56·46	58·90	61·51	64·28	67·21
10	81·06	83·10	85·23	87·46	89·77	92·20

This Table may be used for interpolating the tensions with any standard tension from 20 to 45 lbs. for riband weighing 1 lb. per chain. For riband of any other weight the tension for both the supported and the suspended riband will be proportionate, and may be found by multiplying the quantities in the Table by the *weight of 1 chain of the riband* expressed as a *fraction of a pound.*

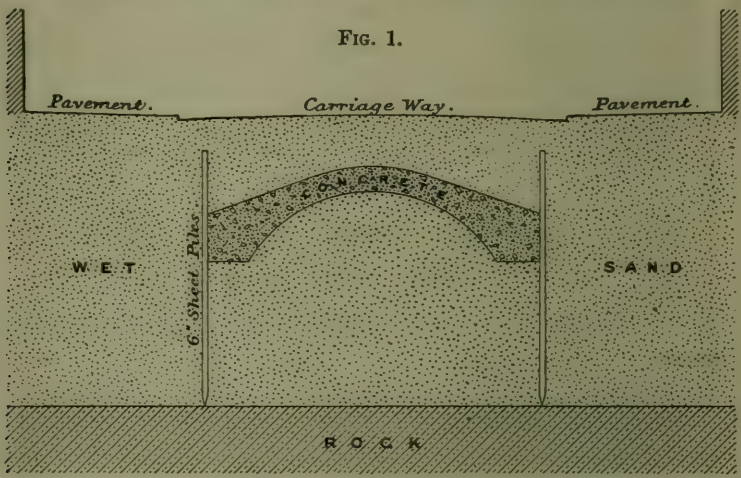
(Paper No. 2288.)

"Covered Way as Constructed on the Glasgow City and District Railway."

By WALTER STUART WILSON, M. Inst. C.E.

THE Glasgow City and District Railway is a short line 2½ miles long, running east and west, principally underground, which has recently been made to connect the railways which terminated at

FIG. 1.



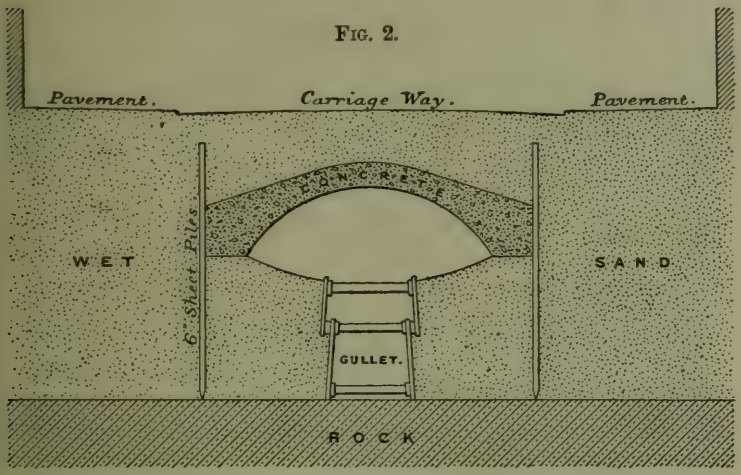
College and Stobcross Stations, some distance from the centre of the city.

The length in tunnel is 2,600 yards, of which 1,050 yards were built by the process of "cut and cover," which it is now proposed briefly to describe.

In Kent Road, near the western end of the line, the railway follows the course of the street for a distance of 700 yards in a straight line. The depth from the surface of the street to the rock, which is nearly at formation-level, varies from 22 to 32 feet. All the material above the rock having been proved to consist of wet sand and mud, it was decided to drive a row of 6-inch sheet-piles at the back of the walls, at each side of the covered way.

This was done without difficulty at the rate of from 9 to 10 feet a day for each piling machine.

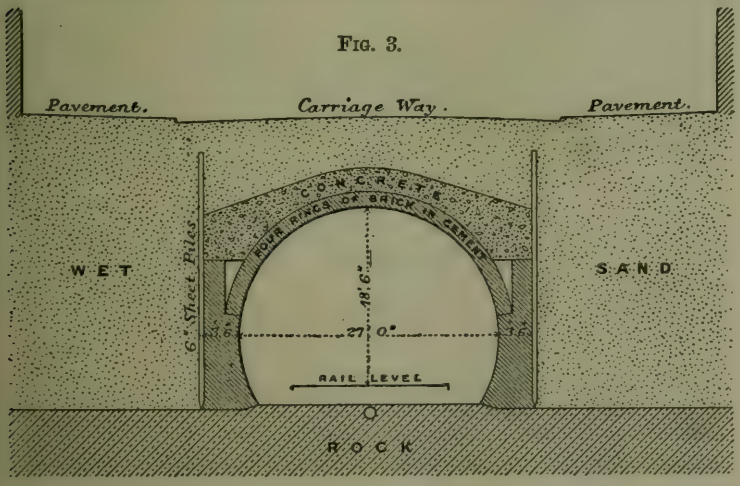
FIG. 2.



Scale: $\frac{1}{240}$.

When a portion of the piling was finished, the Contractor began to sink a trench for the side wall, timbering in the usual way. On

FIG. 3.



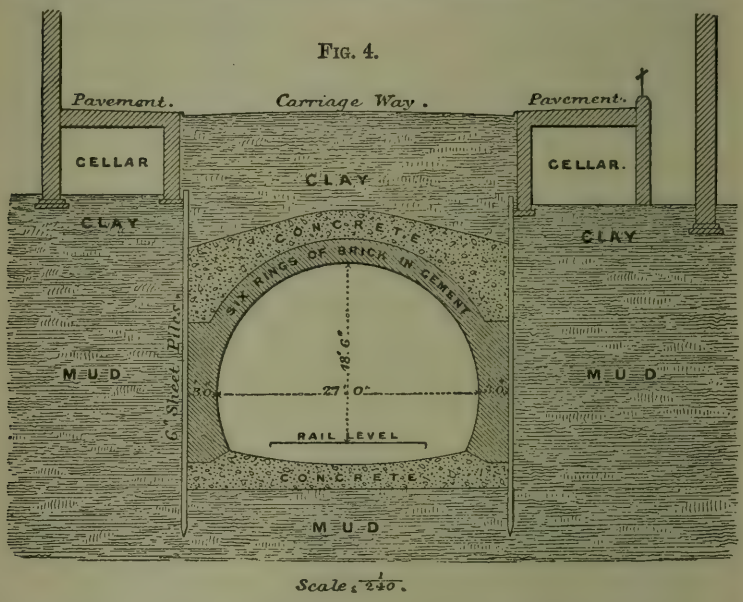
Scale: $\frac{1}{240}$.

the excavation reaching the level of the sewers a considerable quantity of water had to be dealt with.

In pumping this water it was found impossible to prevent the sand from running through the piling, so this mode of working was abandoned. At this time the sewer for the permanent drainage of the railway was being constructed, and it was resolved to delay the work of building the side walls of the covered way until the sewer was completed, so as to avoid all further pumping.

In the meantime, with the object of afterwards facilitating operations, as well as to ensure the safety of the adjoining buildings, many of which were large and valuable, it was decided to

Fig. 4.



form a continuous safety arch of concrete between the two rows of piling. This was done by removing the surface to the proper level and form of the arch. Concrete was then filled in, and the causeway restored so as to allow the vehicular traffic to be resumed (Fig. 1).

The safety arch, 700 yards in length, was carried out in the eight months from April to November 1884.

In May 1884 the drain leading to the River Clyde being now available, tunnelling was begun under the concrete arch. Pits were sunk at the cross streets, from 150 to 300 feet apart, and the materials removed by portable steam-cranes. The "gullet" (Fig. 2) was always kept well ahead of the side walls, in order that the sand and mud might be thoroughly drained before the

sheet-piles were exposed. The work was carried on satisfactorily and rapidly, the wings being removed and the side walls and arch built at the rate of about 200 feet per month, and the 700 yards at this place were completed in April 1885. Fig. 3 shows the completed covered way.

At two other points on the railway the same method was followed, but the bottom being composed of mud, it was found necessary to put in a concrete invert (Fig. 4).

The Paper is accompanied by four diagrams, from which the Figs. in the text have been prepared.

(Paper No. 2294.)

"Castletown Swing-Bridge."

By Charles Wawn, M. Inst. C.E.

In September 1886, the Isle of Man Harbour Commissioners invited designs and estimates for a swing-bridge to carry the high-road across the harbour at Castletown, on the site of a stone arched bridge, then about to be removed in consequence of the extension of the harbour: and a design prepared by the Author on behalf of the Patent Shaft and Axletree Company, Limited, of Wednesbury, was accepted. The bridge is small, and the Author would not have considered it of sufficient importance to be brought before the Institution but for a peculiarity in the turning-gear, to be afterwards described.

The general features of the bridge are so clearly shown by Plate 4 that little description is necessary. It is 64 feet long, and has a clear opening of 26 feet. There are two single-web main girders 4 feet deep. The cross girders are 1 foot 9 inches deep and 6 feet apart; those at the ends are considerably curved, and are braced horizontally to keep them in shape. The roadway, which has a rise of 2 inches in the centre, is intended for moderately heavy traffic, and is paved with 5-inch wood blocks 3 inches wide, run with sand and hot pitch and tar. Under these is a layer of red-wood 1 inch thick, laid crosswise on main longitudinal timbers of pitch-pine, 16 inches wide by 5 inches deep, all well paid with hot pitch and tar. Strong chequered castings of the proper radius and camber confine the paving sets at each end of the bridge, and corresponding castings are bolted to the abutments to keep up the road metal.

The turn-table consists of a live ring of sixteen cast-iron rollers 18 inches in diameter, travelling on a cast-iron path 14 feet in diameter. The upper roller-path, which is also of cast-iron and of a comparatively deep girder section, is in seven segments, this odd number agreeing best with a symmetrical arrangement of the small bearing girders above. It is held in position by rods 2 inches in diameter radiating from the centre pivot. The pivot rests on a block of hard limestone, and is secured by six $1\frac{3}{4}$-inch bolts, and by cleats let into the stone. The lower roller-path is bedded on cement concrete.

The turning-gear consists of spur-gearing, worked by hand from a small platform on that side of the bridge which is towards the shore when it is open. The peculiarity in the gearing previously referred to, consists in the rack being fixed to the live ring instead of to the masonry below. It thus travels round with the bridge, but of course at only half the speed. The arrangement is compact, and, as regards the ironwork, completely self-contained, admitting of perfect fitting and adjustment before leaving the builder's yard. At first sight there appears to be a loss of power, but a little consideration shows that this is not so; for, although it is necessary to apply greater pressure to the teeth of the rack than if it were fixed on the ground, the bridge adds the motion of the rack to its own motion and travels at proportionately greater speed. Thus a rack of 45° range carries the bridge through 90°. The total weight of the bridge including ballast is about 80 tons, and it can be easily turned by one man in less than ninety seconds.

The same system of turning-gear, which is a patent, has since been applied to a larger bridge, the ironwork for which has just been completed by the same Company.

When in position for traffic, the ends of the Castletown bridge are supported on movable cast-iron blocks worked from the same platform as the turning-gear. The two blocks at each end are connected by a weigh-bar and worked by the same handle. The gear used is the worm-and-wheel, which also holds the blocks in place and prevents their working back.

The wood pavement, and the arrangement for working the end blocks from the centre platform, were not part of the original design of the bridge. They were added at the instance of Mr. James Walker, M. Inst. C.E., Engineer to the Isle of Man Harbour Commissioners, under whose general specification and inspection the work has been carried out.

The bridge was opened to the public in May 1887.

The Paper is accompanied by a drawing, from which Plate 4 has been engraved.

(*Paper No. 2299.*)

"On the Heating of Carriages by Exhaust Steam on the Caledonian Railway."

By DUGALD DRUMMOND, M. Inst. C.E.

THE steam used for heating the carriages is taken exclusively from the Westinghouse brake-engine exhaust, which is found to be sufficient. When this source is not available, the engine exhaust is used. In both cases an auxiliary supply-pipe from the boiler is connected to the heating main, and is used as supplementary, if necessary, to the Westinghouse exhaust; and entirely with the engine exhaust for heating trains at terminal stations before starting, or when running without steam on falling gradients.

The steam is conducted from the engine through a wrought-iron pipe of 1-inch internal diameter, fixed to the under-frame of each vehicle. The continuity between the vehicles is effected by flexible india-rubber piping with gun-metal couplings, similar in design to those of the Westinghouse pressure-brake, but with metallic faces. Westinghouse coupling-pipes disused for brake purposes are also employed. As the couplings occupy the lowest points in the main pipe, a hole $\frac{1}{16}$ inch in diameter is provided to keep the depression free from water by condensation. The main steam-pipe under the carriages is covered with felt, with an outside covering of canvas to hold it together.

Each carriage compartment has a thin cast-iron cylindrical reservoir, with an external surface of 8·25 square feet, placed transversely, and under one of the seats. The reservoirs are arranged in pairs, so that one branch from the main pipe supplies steam to two compartments.

The reservoirs have a fall of $\frac{1}{2}$ inch in their length, and a hole $\frac{1}{16}$ inch in diameter at the lower end, passing through a branch carried under the floor, and always open to the atmosphere to allow the air and the water by condensation to escape. The proportion of heating-surface to the cubic capacity of a compartment is 1 square foot of the former to 43 cubic feet of the latter. Each compartment has 20 square feet of glass surface.

With the above proportions a maximum temperature of 62° Fahrenheit can be maintained during the most severe weather experienced in the North on the Caledonian Railway system.

The net cost of fitting an engine and tender and carriages is £4 9*s.* for the former, and £1 16*s.* per compartment for the latter.

Twelve trains, heated on this system, have been running for three winters, and have given so much satisfaction that the Directors have ordered all trains to be similarly fitted. It had been first arranged to open and close the passage of the exhaust steam into each compartment of the train, so as to maintain a uniform temperature of 60° Fahrenheit; but the Author came to the conclusion that such a contrivance would be difficult to keep in order; for, since the pressure of steam in the boiler is almost constant, the exhaust from the cylinder varies in pressure from the front to the rear of the train. It only remained to provide heating surface sufficient to keep the compartments up to the temperature required during winter weather, and so do away with any self-regulating contrivance, which, in railway working, is only a source of trouble. The proportion of heating-surface to cubic capacity of space has given entire satisfaction, and the passengers, without receiving any instructions as to the working of this arrangement, have, of their own accord, regulated the temperature of the compartment by means of the ventilator over the door.

The following results were obtained from a train of five carriages fitted with the apparatus described above. The train, with the exception of the brake third-class at the front and rear, consisted of renewed stock. The experiments were conducted with the train at rest, and the temperatures ascertained simultaneously at intervals of five minutes by an observer in the centre compartment of each carriage. Thermometers were placed in the transverse centre of the carriages, with the bulb resting on the seat and the tube supported by the back-cushion, so that the convection currents from the heat-reservoir under the seat were diffused before affecting them. All the windows and ventilators throughout the train were kept closed. The steam-pressure in the boiler was maintained at 150 lbs. per square inch.

In the first experiment, heating was effected with steam from the boiler through an auxiliary pipe $\frac{1}{4}$ inch in internal diameter, connected to the main pipe under the foot-plate. As mentioned above, this method is never employed exclusively; in this case it was tried so that a comparison might be instituted with the Westinghouse-brake engine-exhaust. The results obtained are given in Fig. 1, Diagram No. 1. It should be mentioned that none of the compartments were precisely alike in respect to the ingress and egress of cold and hot air.

FIG. 1.

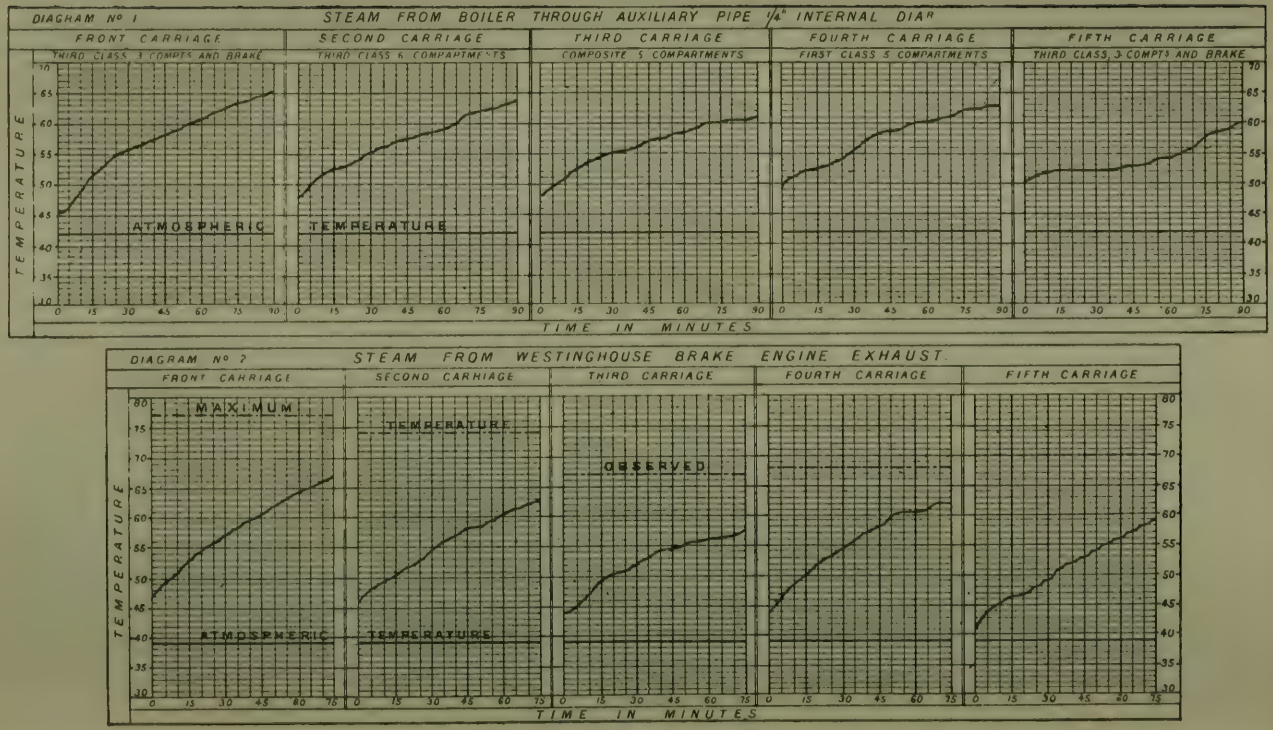


DIAGRAM Nº 1
STEAM FROM BOILER THROUGH AUXILIARY PIPE 1/4" INTERNAL DIAR
FRONT CARRIAGE
THIRD CLASS 3 COMPTS AND BRAKE
SECOND CARRIAGE
THIRD CLASS 6 COMPARTMENTS
THIRD CARRIAGE
COMPOSITE 5 COMPARTMENTS
FOURTH CARRIAGE
FIRST CLASS 5 COMPARTMENTS
FIFTH CARRIAGE
THIRD CLASS 3 COMPTS AND BRAKE
TEMPERATURE
ATMOSPHERIC
TEMPERATURE
TIME IN MINUTES
DIAGRAM Nº 2
STEAM FROM WESTINGHOUSE BRAKE ENGINE EXHAUST.
FRONT CARRIAGE
SECOND CARRIAGE
THIRD CARRIAGE
FOURTH CARRIAGE
FIFTH CARRIAGE
MAXIMUM
TEMPERATURE
OBSERVED
ATMOSPHERIC
TEMPERATURE
TEMPERATURE
TIME IN MINUTES

FIG. 2.

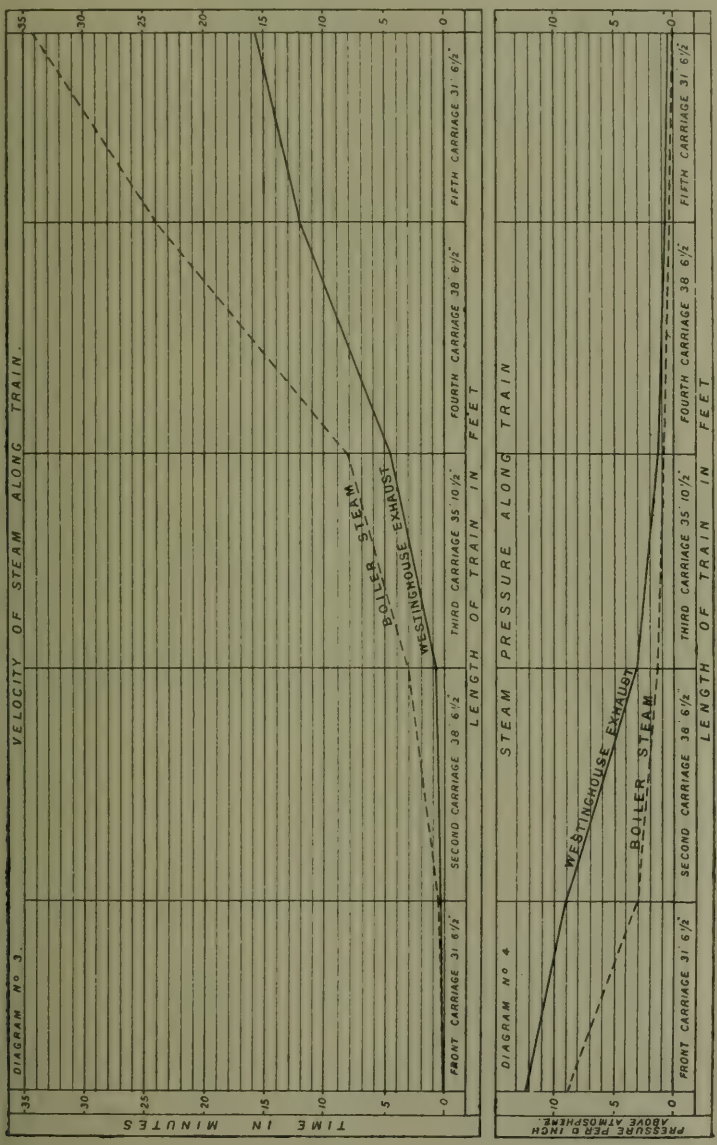


DIAGRAM N° 3.
VELOCITY OF STEAM ALONG TRAIN.
TIME IN MINUTES
35
30
25
20
15
10
5
0
BOILER STEAM
WESTINGHOUSE EXHAUST
FRONT CARRIAGE 31' 6½"
SECOND CARRIAGE 38' 6½"
THIRD CARRIAGE 35' 10½"
FOURTH CARRIAGE 38' 6½"
FIFTH CARRIAGE 31' 6½"
LENGTH OF TRAIN IN FEET
DIAGRAM N° 4
STEAM PRESSURE ALONG TRAIN
PRESSURE PER □ INCH ABOVE ATMOSPHERE
10
5
0
WESTINGHOUSE EXHAUST
BOILER STEAM
FRONT CARRIAGE 31' 6½"
SECOND CARRIAGE 38' 6½"
THIRD CARRIAGE 35' 10½"
FOURTH CARRIAGE 38' 6½"
FIFTH CARRIAGE 31' 6½"
LENGTH OF TRAIN IN FEET

In the second experiment, the heating was accomplished with steam from the Westinghouse-brake engine-exhaust. The pump was working at the rate of 50 double strokes a minute, against an air-pressure of 75 lbs. per square inch. The results are shown by Fig. 1, Diagram No. 2. The relatively low temperature, of the centre compartment of the third carriage, was due to one of the windows having been $\frac{1}{16}$ inch open at the bottom; it was not observed till near the end of the experiment, and was allowed to remain open. This shows that the temperature may be efficiently controlled by means of the ventilators. The highest temperature recorded, but not necessarily the highest attainable under the atmospheric conditions existing, is shown in dotted lines. It was taken one minute after the door had been open for ten seconds.

Fig. 2, Diagram No. 3, shows the velocity of the steam along the train. The points observed were the couplings between the vehicles, which have the hole $\frac{1}{16}$ inch in diameter to allow water by condensation to escape. The time noted was the first appearance of vapour at the hole above-mentioned.

Fig. 2, Diagram No. 4, gives the steam-pressure along the train. The points observed were the same as the preceding, namely, the couplings between the vehicles. A Bourdon gauge was used to ascertain the pressure, and was checked by simultaneous observations of the temperature of the steam at the same point.

The Paper is accompanied by a sheet of illustrations, from which the Figs. in the text have been prepared.

(*Paper No. 2303.*)

"On a Dipping- or Fog-Apparatus for Electric Light in Lighthouses."

By Charles Alexander Stevenson, B.Sc., F.R.S.E., Assoc. M. Inst. C.E.

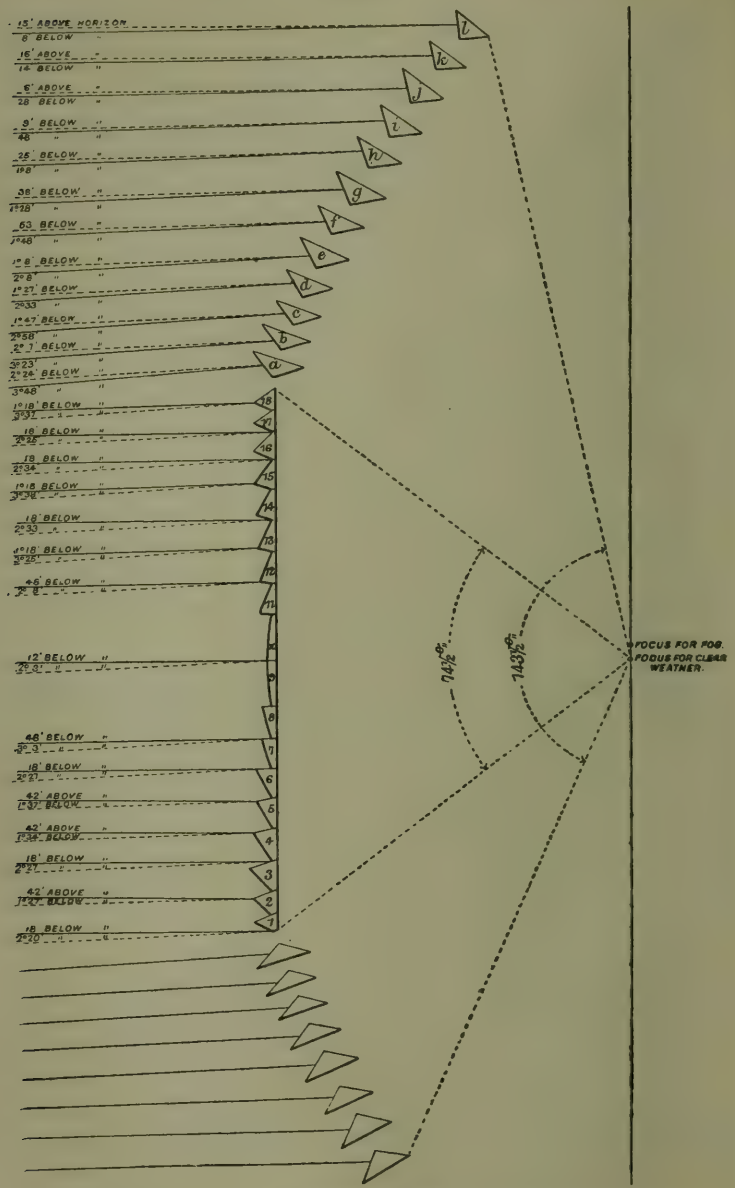
In 1878 the late Mr. Thomas Stevenson, M. Inst. C.E., suggested the system of dipping lights temporarily during fog, so as to send the strongest rays from the apparatus to a part of the sea close to the lighthouse, where, at such times, they would alone be useful.[1] The adoption of this suggestion is indeed almost imperative in the case of electric light, as the dazzling effect close at hand, if the light is uniformly distributed over the sea out to the horizon, becomes so great as to be even a source of danger to navigation.

The power of dipping a light in fog may with propriety be left in the hands of the keepers of an electric light, as the management is usually entrusted, in such cases, to more experienced and trustworthy men. The following method, which the Author has devised for dipping the light, seems to be superior to any that has yet been proposed for effecting this purpose. It involves practically no loss of light, and only needs an alteration in the position of the radiant with respect to the focal plane. All former proposals have been devised on the supposition that it was impossible, by simply raising the focus, to dip the beam and yet keep all the rays emerging from the apparatus still on the sea; as the effect (owing to the prisms being so formed) of raising the burner, so as to depress the light from the belt, naturally caused the light from the upper and lower prisms to go to the sky and be lost.

In the design shown by Fig. 1 (p. 300) the refracting portion of the apparatus, however, has been so calculated as to have a certain vertical divergence, about 2°, and set so that the uppermost ray of the 2° goes to the horizon, or, as in the design, 30′ above the focal plane, the lowermost thus going to 1° 30′ below it, while the upper and lower catadioptric prisms are calculated and set so as to send their light from the horizon to about 3° 30′ below the focal plane, or to the point on the sea nearest the lighthouse which it is

[1] *Nature*, November 7, 1878.

FIG. 1.



Scale, $\frac{1}{10}$ full size.

The continuous lines show rays in clear weather, the dotted lines when dipped in fog.

Fig. 2.

REFRACTING BELT *(in clear weather)*

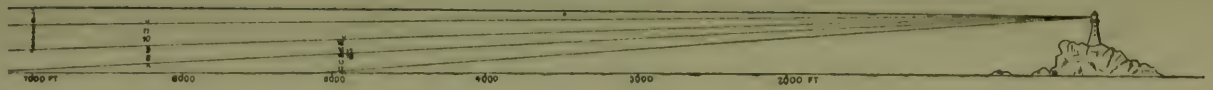


Fig. 3.

REFRACTING BELT *(in fog)*

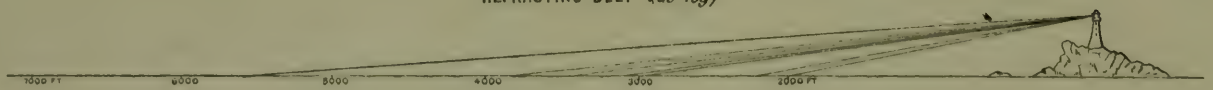


Fig. 4

UPPER CATADIOPTRIC PRISMS *(in clear weather)*
(The lower catadioptric prisms break joint with these)

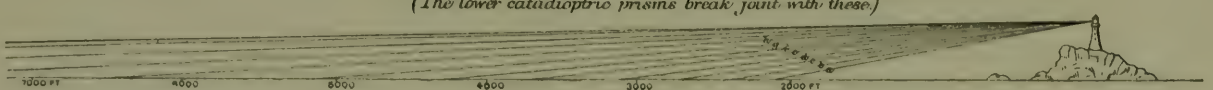
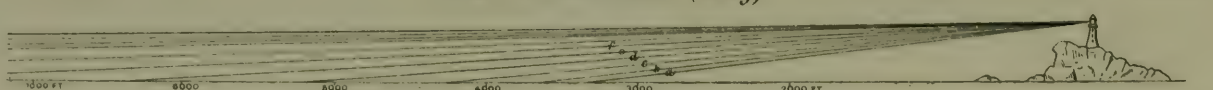


Fig. 5.

UPPER CATADIOPTRIC PRISMS *(in fog)*



necessary to illuminate for safe navigation. This is the condition of matters in clear weather, and by it the best conditions are fulfilled, namely, the strongest light is sent to the horizon, while the near sea is less strongly illuminated. In fog the radiant is raised about 1 inch, with the result that the light from the refracting belt, which is by far the strongest part of the light, is dipped close to the bottom of the tower, or at least to the point of safe navigation. The upper reflecting prisms from *e* to *l* take up the lighting where the uppermost ray of the belt ends, these prisms causing the light to extend to the horizon, or rather a little above it, as the top prisms now will show just a little higher than they did when the focus was adjusted for clear weather. It will be noticed (p. 301), from a comparison of Figs. 4 and 5, that the lowermost ray from these prisms is moved out only 300 yards on the surface of the sea, so that by this system the prisms *a*, *b*, *c*, *d*, *e* still remain in fog to strengthen the light from the belt. The lower prisms, as far as they reach down, act similarly to the upper prisms, and as it were break joint with them.

The effect is graphically shown by Figs. 2, 3, 4 and 5. Fig. 2 shows that the belt lights the sea in clear weather from about 1 mile from the lighthouse out to the horizon, distant 14 miles; and Fig. 3 that the belt in fog illuminates from 2,000 feet out to about 1 mile. Fig. 4 shows that the upper and lower prisms illuminate the sea from 2,000 feet out to the horizon in clear weather; and Fig. 5 that in fog they illuminate the sea from 3,000 feet out to the horizon. Rays are thus thrown on the horizon, in clear weather, from the belt and from the uppermost catadioptric prisms. In fog there is thrown down on the near sea the intense ring of light from the refracting belt, and from the best of the upper and lower catadioptric prisms, while the horizon is never wholly deprived of light, which is a most important matter, it still continuing to be lighted by the upper catadioptric prisms.

The design shown by Fig. 1 is suited for an alternating-current machine, and is calculated for a light 150 feet above sea-level, being the average height of lighthouses in Scotland, and thus having a horizon range of 14 miles with a visible dip of the sea horizon of about 12′. The apparatus is 1,400 millimetres (55·119 inches) in diameter, the refracting portion subtending an angle of 74° 30′, practically the angle recommended by Mr. Allard[1] as that of the greatest efficiency for the belt. The absolute apportioning of the

[1] "Mémoire sur l'intensité et la portée des Phares." Par M. E. Allard. Paris, 1876.

light on the sea is a matter whereon there may be great variety of opinion. But there is the means, by this design, of so altering the level of the focus, and calculating the prisms, as to produce any disposition of light required; and, of course, each case needs a different adjustment of prisms to suit the height of tower and distance of outlying dangers.

After submitting the above Paper to the Institution, the Author received from Sir James N. Douglass, M. Inst. C.E., a copy of his Report of the 23rd of June, 1885, to the Trinity House, from which it will be seen, by the extract quoted below, that Sir James suggested the system which the Author now proposes; but as the design of the apparatus differs from, and is in the Author's opinion superior in some respects to, what had, unknown to the Author, been suggested by Sir James, and is now, for the first time, worked out and put in a practical form, he thinks the account of it will be of interest to those engaged in designing lighthouse apparatus. Sir James N. Douglass says: "It appears to me that the most simple and effective arrangement for dipping the light during fog is to be effected by normally focussing the upper and lower prisms (or 30 per cent. portion) at the extreme dip required for fog, and the refractors (or 70 per cent. portion) at or a little below the sea horizon. During fog the carbons would be raised so as just to reverse the direction of the light from the reflecting prisms and refractors, the former, representing 30 per cent., being sent near the horizon, and the latter (or 70 per cent.) being sent to the near sea." Sir James, in his letter sending his Report, adds: "You will observe from the foregoing that my suggestions for dipping were in accordance with what you propose."

The Paper is accompanied by two sheets of illustrations, from which the Figs. in the text have been prepared.

(*Paper No. 2310.*)

"Electrical Tramway in Hamburg."

By J. L. HUBER.

MANY efforts have been made of late years to adopt electricity for working tramways. Overhead and underground conductors have been, and are still, employed; but the difficulty is to find a substitute for horse-power in the crowded streets of large towns, where overhead conductors are not admissible, and where those laid underground are exposed to a multiplicity of evils only known to those who have endeavoured to cope with them. In this field the storage-battery alone could compete with horse-power, and then only when the energy is stored in a properly controllable form. The Author ventures to say that every practical engineer, knowing the conditions which exist in large towns, will agree with him that any vehicle destined principally for the transport of passengers should be, when possible, independent and self-contained in its motive-power. It is unadvisable to depend upon an engine located at a distance, a breakdown in which, or defects in the leads, would interrupt the service of the whole line. These views influenced him in choosing the Julien system for introduction into Hamburg. A Paper read before the Society of Arts by Captain Douglas Galton, on the 20th of January, 1886, fully describes the Julien system.[1] The speciality of the system is that accumulators, in which the energy is stored, are used in different groups, which may be placed in parallel or in series, according to the power required. This is accomplished by a special switch under the control of the driver, and without any artificial resistance. Only one electric motor is necessary, the power from which is transmitted by ropes to a counter-shaft, and from this by a pitch-chain to one of the axles.[2] Plate 5, Figs. 1, 2, 3, represent the first car (No. 61) in use at Hamburg; it is similar to that exhibited at Antwerp in 1885. The weight of this car is, ready for service, 4·83 (metric) tons, of which

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[1] Journal of the Society of Arts, vol. xxxiv. p. 157.

[2] Elektrotechnische Zeitschrift, Berlin, 1887, p. 222; and Zeitschrift des Vereins Deutscher Ingenieure, 1887, p. 332 and Plate 9.

the accumulators come to 1·2 ton, and the weight of the series-wound motor of Messrs. Siemens Brothers, London, to 572 lbs. The accumulator-battery is placed in eight drawers, with slide contacts; in each drawer there are four boxes, with three cells, and with fifteen plates in each cell, consequently there are ninety-six cells. The whole battery is divided into four parts of twenty-four cells each; these four parts may be arranged, by simply turning the Julien switch, either (1) all four in parallel, giving a current of $24 \times 2 = 48$ volts tension; or (2) two and two parallel, and then in tension = 96 volts; or (3) two in parallel behind the two others, in tension = 144 volts; and (4) all four in tension = 192 volts. The capacity of each cell is 92 ampere-hours, and consequently the amount of stored-up energy is $192 \times 92 = 17{,}664$ watt-hours. The tramway-line selected for the trials with the electrical traction extends from the Rathhausmarkt, in Hamburg, to the Berthastrasse in Barmbeck, and is 5,360 metres (5,862 yards) long. The steepest incline on the line is 1 in 40 and 100 metres long, but only about 800 metres are level, the remainder being more or less steep inclines, with numerous curves. Thus this line, of which the route for nearly 2 miles lies through crowded streets, presents all the difficulties which tramways have to overcome in large towns, and as the trial has been extended over eight months, May to December 1886, on a common public road, it may be considered a very fair one. During the whole of the trial the engineer in charge recorded the number of watt-hours charged on each battery, to find when it needed re-charging, and the time and length of way which the car had run with the battery before this became necessary. By always putting fully-charged batteries into the cars, the amount of watt-hours put into the accumulators, to replenish them, after having done a certain service, gave a full account of the work done. It showed the energy required for the work, and the variations between the different loads, or the difference of power required to run the car. Before commencing the regular service, the Author made trial trips at night with the car No. 61 from the Berthastrasse to the Rathhausmarkt and back. During these trial trips the car was loaded with iron bars, to represent the full weight with passengers in regular service. The current passed through one of Paterson and Cooper's ampere-meters; the revolutions of the motor were indicated by a tacho-meter of Buss and Sombart, and the tension of the current was controlled by one of Paterson and Cooper's volt-meters. The weight of the car was, on all the trial trips, 7 tons, of which

4·83 tons represented the weight of the car proper, and the remainder that of twenty-nine passengers, one driver, and one conductor, or thirty-one persons at 154 lbs. each. The result was that in running up the main inclines 10,700 watts were used, *i.e.*, 54 amperes at 192 volts; further, that on the level 1,800 watts, namely, 19 amperes, multiplied by 96 volts, were required, and that the dynamo made then 900 revolutions. The ratio between the dynamo and the driving-axle was 1 to 10, the diameter of the wheels being 736 millimetres (29 inches), and the circumference 91 inches. Thus at 900 revolutions of the motor the speed of the car was—

$$\frac{900 \times 2{\cdot}312}{10} = 208{\cdot}080 \text{ metres},$$

or about $3\frac{1}{3}$ metres in one second = 12 kilometres ($7\frac{1}{2}$ miles) in one hour. The speed allowed for the tramcars is 12 kilometres an hour in the town, and 16 kilometres in the suburbs. As the trial trips were made during the night, the Author drove the car at a higher speed. As tractive power he calculated 10 kilograms for every ton of weight, plus 1 kilogram for every millimetre of grade per metre, and per 1 metre of speed per second, or—

$$T = \{(t \times 10) + (t \times g)\}\ s,$$

where T is the tractive power, t the weight in tons of 1,000 kilograms, g the grade in millimetres per metre, and s the speed in metres per second. This formula gives very fair results when the rails are in good condition; but to allow for curves, as well as for dirty rails, it is necessary to multiply the values given by the formula by 1·5. The journey from the Berthastrasse to the Rathhausmarkt and back to the Berthastrasse, equal approximately to 11 kilometres (6·8 miles), occupied fifty-five minutes, and 96,802 + 94,652 = 191,454 watt-minutes were indicated, or 3,481 watts per minute, or 17,405 watt-minutes = 290 watt-hours for every kilometre. As during the trial the accumulators were in first-rate condition, an efficiency of 80 per cent. could be reckoned on, and thus the accumulators required a charge of 362 watt-hours for every kilometre of way made by the car (7,000 kilos) on the line in question.

As stated above, the output of the accumulators was 17,664 watt-hours, and thus, in every 290 watt-hours per kilometre, 60 kilometres might be run with one load; but as at any moment something might occur on a tramway, and more power might be required to overcome it, the Author did not consider it advisable to allow the accumulator to run so far down; and besides, the

life of accumulators is prolonged when they are never fully discharged.

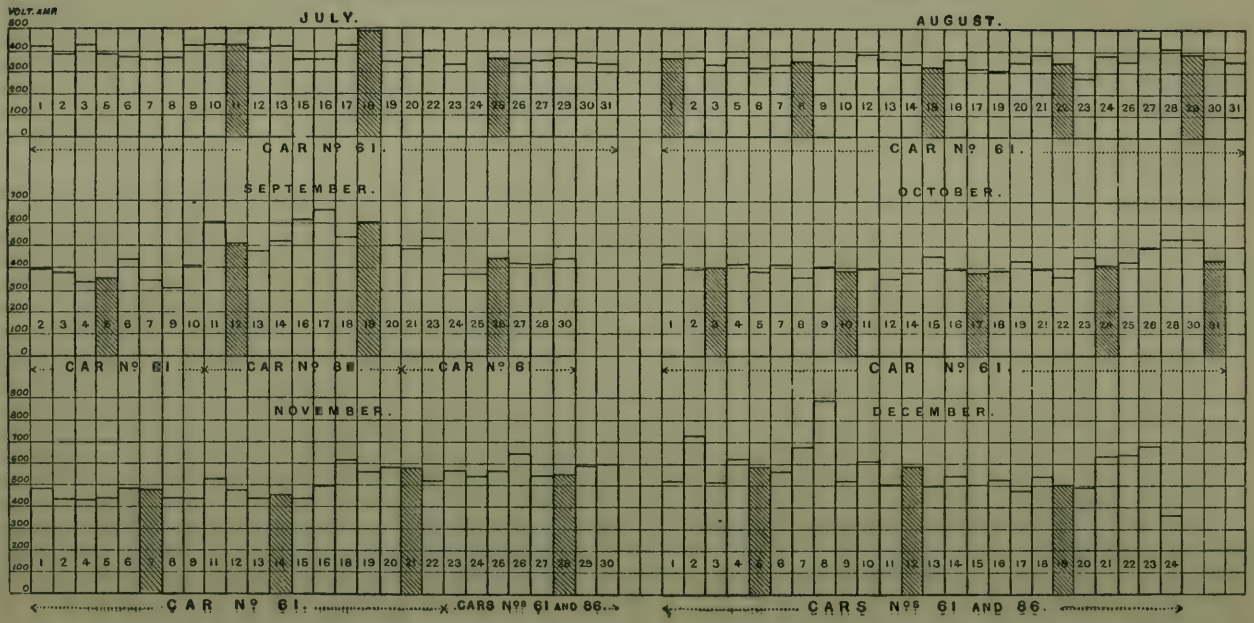
The annexed Fig., p. 308, gives the daily expenditure of energy in watt-hours employed to drive the car 1 kilometre, from the 1st of July to the 24th of December, 1886. The shaded parts of the Fig. represent Sundays; one day in each week is missing, which was either a holiday for the men, or was employed in overhauling the installation. The mean energy expended in volt-amperes to reload the accumulator was: In July, 392·16; August, 354·72; September, 441·49; October, 417·87; November, 701·92; and December, 561·374. The lowest amount of energy for 1 kilometre employed in one day, when only one car, No. 61, was running, was 280 watt-hours, on the 23rd of August, and the highest to the end of October 630 watt-hours. This enormous difference, as well as the daily variations, were due to the state of the rails and the traffic, which were both influenced by the weather. During summer, and in fine weather, the rails are clean, and in Hamburg the streets are well swept and watered; besides, the traffic is small, and the public evenly distributed on both platforms; but if the weather is misty, the rails are slippery, the cars more fully occupied, and the passengers avoid the forward platform and crowd on the hind one. This, when the driven axle is foremost, occasions loss of energy. The worst is when the grooves of the rails are filled with frozen dirt, and this happens in Hamburg when, during the night, sudden frost sets in, and the cars have to commence running before the salt-car, or before the salt has sufficiently acted; such a day was the 8th of December, when the average energy rose to 890 watt-hours.

Now, with an average of 362 watt-hours per kilometre, 19 amperes at 96 volts are employed on the level, and 54 amperes at 192 volts on different inclines, so that there must be, when 630 watt-hours are necessary, an expenditure of at least $\frac{54 \times 630}{362} = 94$ amperes on the inclines; and it is probable that, under bad conditions of the road on the inclines, the amount of power will be still higher than under good conditions, and that a current of over 100 amperes will pass the motor.

An electric current of 94 amperes × 192 volts is equal to an expenditure of 24½ HP., which had been taken out of the accumulators; but this had not been used only as tractive power, for it had heated the motor and had been wasted, and this is the weak point of all electric tramways. Every locomotive and every self-propelling car is made to do a certain amount of work on a

Hamburg Electrical Tramway.

Expenditure of Energy for 1 kilometre, July 1 to December 24, 1886.



certain line, to propel at a certain speed a limited weight on a maximum of incline, that is, at a maximum of resistance of the road; if the weight is constant, and the resistance on the road increased, the speed diminishes, and at last the motor must stand still. In a steam-engine the amount of steam, or energy, that might be taken out of the boiler (the accumulator) depends upon the volume of the cylinders and the number of revolutions. If the engines stand still no revolutions are made, and no steam is taken out of the boilers; and if the safety-valves do not blow off steam, no energy is wasted. Quite different are the conditions of the electric motor; the amount of current that flows through the coils of the motor (for tramcars series-wound motors are to be considered) depends upon the number of revolutions of the armature; and, at the same tension of the current, the greater the number of revolutions the less is the amount of current. Thus, when by increased resistance on the road the speed of the vehicle, and consequently of the motor (armature) diminishes, the amount of current increases and comes to its maximum, which depends upon the internal resistance of the motor when the motor stands still. Every motor is constructed to run at a certain tension of the current, at a certain speed, and will then take a certain amount of current. If, by overloading the car, or over-charging the motor, the speed diminishes, the amount of current will increase; yet the increase of current will perform very little useful work, but heat the motor. The heat partly disappears by radiation, but is, at all events, a waste of energy, and must be avoided.

The appearance of heat or light, where only power is needed, is a waste of energy, and consequently a waste of money. Still, this occurs in a great number of electrical installations, and principally electrical tramways; in these installations a series of artificial resistances are employed, and are more or less thrown into the circuit, according to the amount of current that has to pass the motor to attain a certain speed, or to start. Then, as in those installations the tension of the current is constant, the amount of current that flows through the motor depends only upon the resistance in the leads to be overcome. Then resistances do not act only like a throttle-valve, but they get heated, and this heat must be absorbed by radiation by the surrounding air, otherwise they will melt. In experiments made for this purpose, the Author has melted glass tubes 15 millimetres (0·59 inch) in diameter and 500 millimetres (19·68 inches) long, which he had surrounded with a spiral of German-silver wire 1·2 millimetre (0·05 inch) in

diameter, and imbedded in infusorial earth in a porcelain pipe of the same length, and of 25 millimetres (0·98 inch) outside diameter. The spiral was melted and stopped the experiment, which he repeated several times, varying the tension of the current, and therefore the amount of amperes passing, and consequently the time in which the wire melted. These experiments show what amount of heat or energy is wasted by resistances placed in the current, and that it is wasteful to adopt such means to use up less energy in the motor; it would be like employing a brake to regulate a steam-engine, instead of cutting off and expanding the steam; the resistances in an electric current will do there, because they are simple, where a small amount of current passes them, or where the loss of energy is negligible. To avoid the resistances, Mr. Julien has grouped the accumulators in parallel or in series, as most convenient, and this constitutes one of the great advantages of using accumulators instead of direct current; then by direct current the tension is always constant, and must be so high as to do the maximum of work required on the line, to ascend inclines, or to run with full load at a certain speed. Where this maximum of work is not required, resistances must be introduced. Since, as shown above, the use of the common resistance-spirals is wasteful, the Author recommends, instead of them, accumulators, which, when charged by the necessary surplus of energy in the line, will serve to light the train or otherwise, and so avoid the useless waste of energy. Finally, the amount of power required on different parts of the line may vary very much; but, as it is not necessary to ascend steep inclines at the maximum of speed, the motor or motors may be arranged in such a way that they can do, at a limited speed, the required maximum of work without getting hot, and to effect this the Author proposes the use of two motors instead of one, combined in such a way that one may suffice for the level, or for small inclines, but that the two may be placed in parallel on steep inclines; using, then, the current at half tension, the motors will turn at the lower speed, corresponding at this lower tension, and thus the car will run at lower speed and require less power to ascend the inclines. The simplest way to arrive at this "relay" for common tramcars would be to place two armatures on the same shaft in the same, or in two different magnetic fields. But the two motors should not be placed on two different bogies, as in that case a car would always be liable to run off the rails on sharp curves; the forward motor would, on entering a curve, be relatively the weaker one, as it has to overcome more resistance

than the one behind, and would be easily thrown by the latter off the rails. This is so well known to railway engineers, that he would not have mentioned it had he not seen an electric car arranged in this way, and consequently derailed.

After the first car, No. 61, had been in use some time, the Author arranged a second car, No. 86, for electrical traction (Plate 5, Figs. 4, 5, 6). This car was fitted in a similar way, but the motor was placed between the two axles, and the car had seats for twenty passengers inside; its weight was, ready for service, 6 metric tons, and when loaded with thirty passengers, one driver, and one guard, 8·24 tons; the weight of the accumulators was 1·94 ton, and of the motor 1,188 lbs. The motor was by Messrs. Elwell and Parker, and similarly to those used on the Blackpool electric tramway. A great advantage of these motors is that, instead of using two pairs of brushes, only one pair of contacts is employed to bring the current to the collector of the armature; it is thus possible, in running down-hill, to use the motor as a dynamo, driven by the mechanical energy developed, and charge the accumulators; but further, the motor itself serves as a powerful brake, and he has so employed it many times, when it is necessary suddenly to bring the car nearly to a standstill, to avert damage or accident. The final result of his trials is that to drive a tramcar on a line, for every 220 lbs. of weight and 1,000 metres (1,093 yards) of way, 7·8 watt-hours are required.

This communication is accompanied by several illustrations, from which Plate 5 and the Fig. in the text have been prepared.

(Paper No. 2329.)

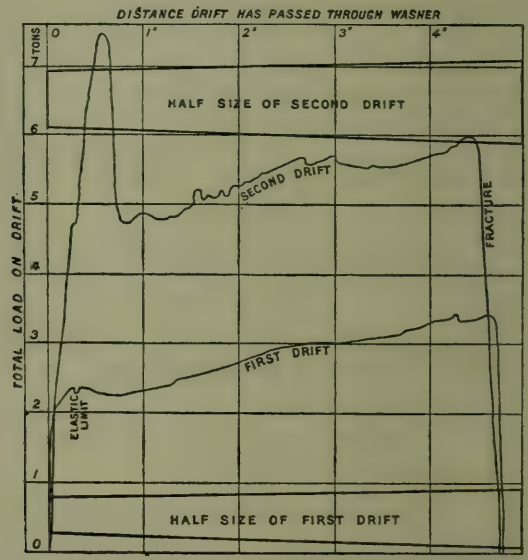
"Autographic Drifting-Tests."

By John Goodman, Wh. Sc., Assoc. M. Inst. C.E.

The Author of this Paper has drifted several washers in a Buckton testing-machine, and from them has taken autographic diagrams (Figs. 1, 2, 3, 4), to show the pressure necessary at each instant to force the drift through the washer.

The drifts were turned with a taper of $\frac{1}{4}$ inch in 5 inches, the smaller of the two tapering from $\frac{3}{8}$-inch to $\frac{5}{8}$-inch in diameter,

Fig. 1.



and the larger from $\frac{5}{8}$-inch to $\frac{7}{8}$-inch in diameter. The sizes of the drifts are also shown, from which the drifted diameter of the hole corresponding to each point in the diagram can be seen at a glance.

In washer Fig. 1 the diagram of the second drift is somewhat irregular. The high load, occurring when the second drift had passed through the first $\frac{1}{2}$-inch, was due to excessive friction; after the drift had been removed from the fractured washer, it was found that the point had seized and become scored in passing through. The other smaller "kinks" in the diagram are also

probably due to the varying frictional resistance, in spite of the

FIG. 2.

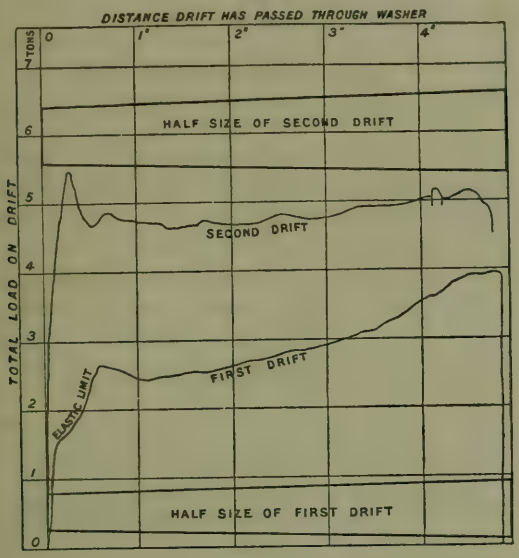
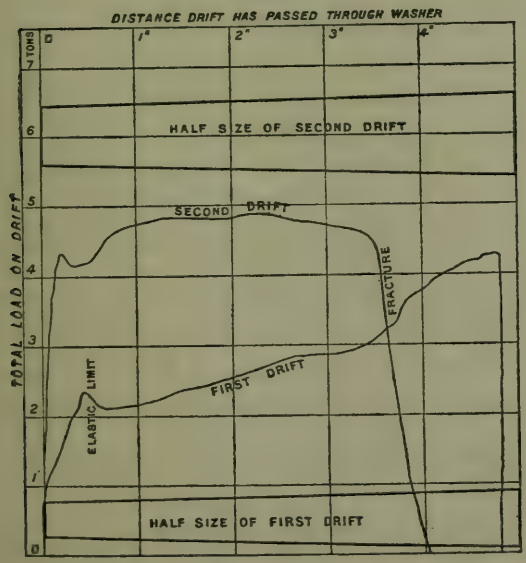


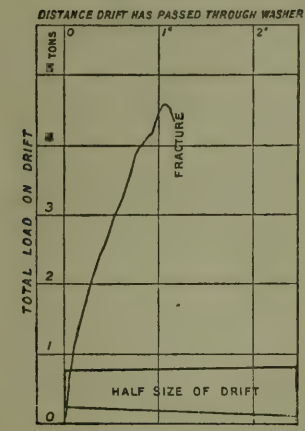
FIG. 3.



drifts being thoroughly oiled. Washer Fig. 2 was not actually

fractured when the second drift had passed through, although stricture had commenced, and it was beginning to crack. Washer Fig. 4 was turned out of a bar of Bessemer steel, the hole being drilled axially; hence the stress acted against the grain, which will account for the very small amount of extension before fracture.

Fig. 4.



In diagrams Figs. 1 and 2 it will be observed that the load at the end of the first drift was nearly 1 ton lower than at the beginning of the second drift. This difference was due to the friction being much higher in one case than in the other; hence the pressure on the drifts is no guide to finding the stress on the washer.

The steel plates from which the washers were cut were kindly supplied by Messrs. Maudslay Son and Field, of Greenwich; the quality of them was the same as those tested by Mr. Goodall.[1] The experiments were made on Mr. Stanger's machine, in the Broadway, Westminster.

The particulars of the specimens, and results of the tests, are given in the following Table:—

Number of Washer.	Thickness of Plate.	Original Diameter.		Maximum Load on Drift.	Final Diameter.		Extension.		Reduction in Area.
		Hole.	External.		Hole.	External.	On Fibres round Hole.	On External Fibres.	
	Inch.	Inch.	Inch.	Tons.	Inch.	Inch.	Per cent.	Per cent.	Per cent.
I.	0·950	0·412	1·011	5·99	0·856	1·300	107·8	28·6	51·8
II.	0·874	0·409	1·009	5·16	0·880	1·320	115·2	30·8	53·7
III.	0·685	0·409	1·012	4·85	0·836	1·290	104·4	27·5	46·1
IV.	Length. 1·024	0·405	1·013	4·54	0·439	1·022	8·4	0·88	6·46

The Paper is illustrated by four diagrams, from which the Figs. in the text have been prepared.

[1] Minutes of Proceedings Inst. C.E. vol. xcii. p. 3, *et seq.*

(*Students' Paper No. 229.*)

"The Classification of Continuous Railway-Brakes."[1]

By Arthur Wharton Metcalfe, Stud. Inst. C.E.

Many persons may have been struck with the resemblance between some of the best-known systems of continuous railway-brakes in daily use, without being able to determine precisely what constitutes the difference. Thus the vacuum, the compressed-air, steam and hydraulic-brakes, together with their many modifications, are generally spoken of as differing in principle of action, instead of as differing in the mode of application of the same principle, which they do in reality.

No systematic classification of brakes has yet been made on a method sufficiently broad to include all those which have been invented, or are now in use, or which affords grounds for the belief that it is comprehensive enough to include such as may yet appear. The object of this Paper is to discuss:—

I. The kinetics and the general principles involved in the problem of retarding the motion of a train, particular reference being made to the bearing that the law of the conservation of energy has upon the design of brake mechanisms.

II. The principles of action which enter into the design of brakes, and of which the various systems are only so many different modes of application, however much the principles may at first appear to be obscured.

III. A classification based upon these principles of action, the practical use of which classification will be illustrated by an analysis of the best-known systems in general use, as well as by a brief reference to such obsolete forms as, though differing from existing forms, may serve further to illustrate its breadth of application.

This classification is similar to the one proposed by Mr. John Wolfe Barry, M. Inst. C.E.,[2] but the details have been more completely worked out, and have also been enunciated in general terms by the late Professor Rankine.[3]

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[1] This communication was read and discussed at a meeting of the Students on the 2nd of December, 1887.

[2] "Railway Appliances," 1876, p. 288.

[3] "Civil Engineering," 1863, p. 644.

Section I.

From the fact that any object when moving accumulates work, the kinetic energy of a moving train may, by means of suitable contrivances, be made to take various forms, conditionally by parting with its velocity. The accumulated work of the train must be in this way given out, and until the energy, stored in the train at the maximum speed it had attained when the brakes were applied, has been completely dispersed, the train will not come to a standstill. Strictly speaking, then, a brake may be defined as a mechanism designed to retard the speed of a train, by absorbing, dispersing, or transforming the kinetic energy due to its speed.

As may be expected from such a comprehensive definition of the term brake, it may appear in forms which will hardly be recognized by those who have only been in the habit of thinking of it as usually represented.

The speed of a train may be reduced in two ways: The kinetic energy may be directly dispersed as heat, light, or in overcoming prejudicial resistances of the brake-mechanism, or in doing work. Or it may be stored, and then dispersed, as in weights lifted, springs or gases compressed, or electricity stored in secondary batteries, all of which constitute stores of potential energy.

Recurring now to the brake-mechanism, whose function it is to disperse the energy of the train, and regarding it as a complete machine, it will be found, like all others, to consist of three principal parts, according to the duties performed by each. The three parts have been thus named:—The "Receptor," that part of the machine to which the available force is applied; the "Communicator," that part of the machine which serves to transmit the available force from the receptor, with increased force and diminished speed, to the working part, or "Tool."

In brakes the tool assumes the form of brake-block, slipper, rail-clip, water or other instrument, according to the nature of the resistance to be overcome, by which the energy of the train is to be dissipated.

It may be thought that a classification of brake-mechanisms based upon the particular form of tool necessary to carry out the absorption, dispersion, or transformation of the kinetic energy of the train, would have formed a good basis for classifying brakes; this is not, however, the case.

Such a classification has been proposed and adopted for "Sectional brakes," by which term those brakes are known which are

only fitted to particular vans in a train, and which are therefore independent of each other in their action; and to such brakes which, when used on a portion of a train of a few carriages, are only useful when the carriages are connected with a van which contains the power and gear necessary for their application.

Among sectional brakes there is considerable diversity in the pattern of the tool in use, so that block-, clip-, fan-, and pump-brakes figure in the list. Descriptions of these will be found in the work previously referred to.[1]

The form of tool depends upon the nature of the resistances to be overcome; it will be sufficient to indicate these in two or three instances.

In the slipper-brake, where the brake-van is lifted and its weight transferred from the wheel to the slipper, the energy of the train is consumed in overcoming the friction of the weight of the van into the coefficient of friction for the metal slipper sliding on the metal rail.

In the clip-brake, the energy dispersed consists of that part consumed in overcoming the resistance of the clip gripping the rail, and that which produces strain in the various parts of the mechanism, owing to the stress to which they are subjected on a sudden application of the brake. The classification of brakes by Reuleaux[2] contains some important remarks bearing upon clip- and band-brakes.

Lastly, in the pump-brake,[3] the work done in dissipating the energy of the train is that of overcoming the fluid-friction of the water pumped through a plate perforated with small holes, the pump being worked from the brake-van axle.

Sufficient has been said to justify the classification of sectional brakes, which is based upon the form of tool employed in the various kinds of brakes for dispersing the kinetic energy of the train.

By "Continuous brakes" are understood those mechanisms in which the application of the brakes to any part of the train must produce the simultaneous application of the brake-blocks to the wheels of every other vehicle connected with them. It will be found that the mode of classification adopted for sectional brakes no longer suffices, because one pattern of tool has been adopted as the most suitable for dispersing the kinetic energy of

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[1] "Railway Appliances," 1876, p. 288.
[2] "Steam Engine," 1884, pp. 52–56 and 555.
[3] Reuleaux, "Kinematics of Machinery," p. 467.

the train in the minimum of time. In continuous brakes this tool is a brake-block, which is pressed against each wheel when its speed is to be checked, the energy of the train disappearing as heat generated by the friction of the brake-blocks and the wheels.

The communicator does not offer any better ground for the classification of continuous brakes, the transmitting part of the mechanism, or brake-rigging, being much alike in all, particularly in those systems of brakes now in general use.

The part which varies in continuous brakes, and which serves to distinguish one group from another, is the receptor part of the mechanism, where the available force for working the brakes is applied; the receptor therefore furnishes the basis upon which to establish a classification of continuous brakes, its distinguishing features being in each case determined by the nature of the force applied to it.

Before proceeding, it is necessary to examine the Board of Trade conditions relating to continuous brakes, as suggested in the circular letter of the 30th of August, 1877, furnished to the Railway Companies of Great Britain, as these have had great influence in determining the style of brakes now generally adopted. These are:—

(*a.*) The brakes to be efficient in stopping trains, instantaneous in their action, and capable of being applied without difficulty by engine-drivers or by guards.

(*b.*) In case of accident, to be instantaneously self-acting.

(*c.*) The brakes to be put on and taken off (with facility) on the engine and every vehicle of a train.

(*d.*) The brakes to be regularly used in daily working.

(*e.*) The materials employed to be of a durable character, so as to be easily maintained and kept in order.

The condition (*a.*) implies that a class is in use in which the brakes are not continuous. A natural line of division of brakes into two groups is thus suggested, one group including sectional brakes, the other continuous brakes. This distinction leaves each group to be dealt with separately as regards classification. The classification of sectional brakes has been dealt with already, and the variety in form of the receptor, depending upon the nature of the force applied to it, has been indicated as furnishing the key to the classification of continuous brakes.

The condition (*b.*) of the Board of Trade circular suggests a division of continuous-brake mechanisms into simple continuous brakes and automatic continuous brakes; each of these groups is divisible into three classes, distinguishable by the form of the

receptor. The receptor, by which any particular class among the "simple" brakes is defined, serves with certain modifications necessary to enable it to comply with the condition (*b.*), to define also a corresponding class among the automatic continuous brakes.

Section II.

The principles of action entering into the design of brakes will be seen when the classes into which continuous brakes would naturally fall, when arranged according to the basis adopted by the Author, are defined.

The basis adopted is, "The nature of the force available for braking, and the mode of its application to the receptor of the brake-mechanism," and the classes which it suggests are three in number, each class containing simple and continuous brakes of the same type; they are as follow:—

Class I contains brake-mechanisms, in which the available force for stopping the train is the manual power of one or more men applied to hand-wheels in the brake-vans. By means of toothed bevel-gearing, which rotates a long shaft beneath the carriage, the shaft having a screw cut on a portion of its length, the brake-blocks are forced against the wheels of the brake-van. This shaft carries an end coupling, which transmits its motion to similar shafts on the coaches with which it is coupled; or, by means of a continuous chain, which derives its motion from a nut working to and fro on the screw-shaft of the brake-van; the brakes may likewise be made to act continuously over several vehicles.

Class II contains continuous-brake mechanisms, in which the force available for braking is derived from the motion of the train. This force is either the kinetic energy of the train itself, or it is derived directly from the traction of the engine transmitted through the drawbars. The tractive force of the engine, transmitted through the drawbar, deflects laminated springs, whose ends slide in guides placed beneath the under-frames of the carriages, and the brakes are held "off"; when the traction is relaxed, as in descending a gradient, the recoil of the laminated springs applies the brakes. Where the kinetic energy of the train constitutes the available brake-power, it is applied in the following manner for working the brakes:—A driving friction-wheel, keyed to the last axle of the tail brake-van, works against a second friction-wheel; this, the driven one forming the receptor of the brake-mechanism proper, and which wheel is so fitted in a

pendulous frame that it can at the option of the guard or driver (or, in the case of automatic brakes, by accidental separation of the train), be brought into contact with the driving friction-wheel on the brake-van axle. On the same axle as the driven friction-wheel, and firmly attached to its side, is a drum to an eyelet, in the circumference of which the end of a flat-linked chain is attached, the other end being made fast to the main levers of the brake-rigging of the furthest coach to which the continuity of the brakes is to extend. The brake-blocks will move towards the tires of the coach-wheels so soon as frictional contact is made between the driving and driven friction-wheels, when, the chain being wound upon the drum, the motion of the levers actuating the blocks must ensue, and the desired end be obtained.

Class III includes all those continuous-brake mechanisms in which the available force necessary to work the brakes is brought into action, by destroying a certain condition of liquid or fluid pressure or of vacuum on one side of a piston working in a cylinder, or which is attached to its equivalent, a larger metal reservoir, by means of a flexible air-tight diaphragm, this condition having previously been maintained on both sides when the brakes were off. Equilibrium having been thus destroyed, and the force available brought into action, motion of the piston or the cylinder ensues according as the piston or the cylinder is linked to the transmitting section of the brake-mechanism. The Author will illustrate in the next section certain typical examples of simple brakes of the three classes; and, after examining the conditions upon which automatic action depends, will describe the best known automatic brakes of all three classes, to illustrate the mode in which these conditions are complied with in practice.

Section III.

Continuous brakes are here classified and analysed.

Of simple brakes of Class I there is but one true representative, namely, the continuous screw-brake, which has been already sufficiently described in connection with the principle forming the distinctive feature of this class, and of which Fay's and Newall's brake is an example.

Of simple brakes of Class II, the continuous chain-brake has also been described in connection with the principle forming the distinctive feature of the class. The mechanism is sometimes simplified by substituting, for the driving friction-wheel keyed on

the axle and working a second friction-wheel in connection with the chain barrel, one drum only, which rides loose on the brake-van axle when the brake is off; but round which the chain can be wound when the pulley is made fast by a clutch worked from the van for the application of the brakes.

In simple brakes of Class III, whether they be pressure- or vacuum-brakes, the condition maintained on both sides of the piston or diaphragm, when the brakes are off, is identical with that of the atmosphere external to the cylinder; that is, when the brakes are off, the piston or the cylinder, diaphragm or collapsible sack, whichever of these is employed to actuate the brake-lever, is maintained in a condition of stable equilibrium. In order to destroy this condition, for application of the brakes, two methods may be adopted. Either the air may be withdrawn from the cylinders or sacks, and a vacuum, or partial vacuum, maintained on one side of the piston, the pressure of the atmosphere opposing this vacuum constituting the force by which the brakes are applied. Or the pressure on one side of the piston or diaphragm may be increased, so as to exceed that of the external atmosphere opposed to it on the other side of that piston.

Where a jet of water under pressure is used, as in certain hydraulic brakes, a spiral spring helps the piston home when the brakes are to be taken off, as there is a tendency in the brakes to stick on if any water should remain in the pipes connected with the cylinders, on account of the weight of the water. Where horizontal cylinders are used in the Westinghouse brake, the pistons are likewise released by the pressure of spiral springs. As simple vacuum-brakes are all very much alike, a description of one will suffice for the rest. In the "Tell-tale" vacuum-brake a combination ejector on the engine, actuated by a jet of steam from the boiler, is placed in a convenient position on the engine for exhausting into the smoke-box. The ejector is connected with a continuous train-pipe, from which branch pipes lead to the top sides of the brake-pistons. When the brakes are to be applied, air is withdrawn from the brake-pipe and top sides of the brake-pistons by means of the large ejector, the pressure of the atmosphere below the brake-piston pushing it up and applying the brakes. The object of the small ejector, combined with the large one, is to test the condition of the train-pipe or couplings. This it does by creating a few inches of vacuum in the train-pipe, the amount being shown by a pointer indicating "brake right" on the gauge. Should a leak occur in the system, which would impair the efficiency of the brake, the small ejector fails to main-

tain its vacuum, and the pointer shows "brake wrong." In Smith's vacuum-brake one ejector is used and a double line of piping; and in the Hardy vacuum-brake there are two ejectors, one acting upon the engine and tender, and the other acting upon the train-pipe, one line of pipe only being used.[1]

In the Westinghouse non-automatic pressure-brake steam from the boiler is supplied to a cylinder placed vertically above, and exactly in line with, a direct-acting air-compressing pump. This pump forces air into a strong, wrought-iron reservoir placed below the foot-plate of the engine, until the working-pressure of the brake is reached. A continuous pipe leads from this main reservoir to the brake-cylinders attached to the under-frames of the carriages forming the train. When the brakes are to be applied, the driver opens a communication by the valve between the reservoir and the brake-cylinders, the air in the brake-pipe is moved forward and compressed, as is also the air behind the brake-pistons, which move forward and bring about the application of the brakes all over the train.

To release the brakes, the driver cuts off communication between the reservoir and the continuous pipe, the compressed air within the pipe being released by the same or by another valve, and the pressure of the air in the train-pipe reduced to that of the atmosphere; when, stable equilibrium having been restored between the air on both sides of the brake-pistons, they are forced home, and the brakes released by the spiral springs before referred to.

It will be seen that the application of this brake over a long train must be comparatively slow, and the waste of air considerable, because the cylinders have to discharge a large volume of air at high pressure when the brakes are released; again, the brake would be useless, in the event of accidental parting of the train, unless some device was introduced into the design for saving the brake-power on a part of the train. To accomplish this, Mr. Westinghouse resorted to the plan adopted in the case of the continuous screw-brake, namely, that of dividing the brake-power between the front and the rear parts of a train. In addition to the air-reservoir on the engine, an air-reservoir is fitted under the tail van, into which air feeds from the brake-pipe until the proper pressure is reached, a valve similar to the driver's being likewise supplied for the use of the guard. Moreover, valves which are

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[1] For full information concerning vacuum-brakes, see "Continuous Railway-Brakes," by M. Reynolds. 1882.

closed by the pressure within the train-pipe, when communication exists between it and the tail-van reservoir, are placed in the hose couplings. It will thus be seen that should the train become parted the power on the rear severed portion would not be lost, because the air cannot escape from the brake-pipe on the severed portion of the train connected with the tail van, the valves in the hose-couplings being kept closed by the pressure within the pipe, and the air in the guard's-van reservoir being still available for application of the brakes on the hind portion of the train.

Before proceeding to a description of automatic brakes, it will be necessary to examine the conditions upon which automatic action depend. In order that automatic action may become possible, there must be a store of potential energy at the command of the driver or guard, sufficiently large to apply the brakes directly or indirectly throughout the train in cases of emergency.

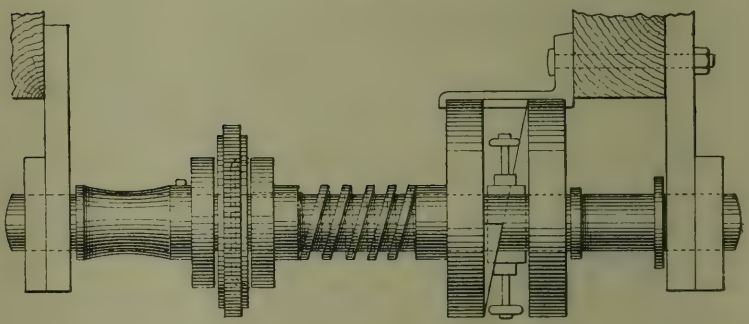
This store of energy should also cause the brakes to be applied automatically on the portion of a train that has become severed, the stored power being released by the accident which has made the use of the brakes necessary. There are two methods of applying this potential energy, for bringing about the automatic action of the brake, according to the amount available for the purpose.

When the amount of power is large, it becomes, when released by the driver or guard, or by accidental parting of the train, the actual force which, applied to the receptor of the brake-mechanism, brings about the application of the brakes to the wheels throughout the train. Where, however, the amount of potential energy, used for enabling the brakes to act automatically when required, is small, it is more conveniently and more properly applied to some adjunct of the brake-mechanism, to bring into action the available force, either kinetic in the case of certain brakes of Class II, or potential in others of Class III, relied on for application to the receptor of the brake-mechanism for working the brakes. The first method of making the brake automatic is followed in those brakes of Class I and Class II, in which powerful spiral or laminated springs are placed in compression, and are kept so by the tension of a chain. The chain, when snapped, by the parting of the train or when purposely relaxed by the driver or guard, releases the work stored in the springs, which, acting at the receptor, brings about the application of the brakes.

The first method is also adhered to in those brakes of Class III known as differential-pressure brakes, where a certain condition of high pressure, or of vacuum, is maintained on both sides of the brake-piston, which is thus kept in unstable equilibrium. The brakes are applied when this unstable equilibrium is disturbed by allowing air to escape from one side of the piston in the case of pressure-brakes, or to flow into the void on one side of the piston in the use of vacuum-brakes.

The second method of making the brake automatic is followed in those brakes of Class II, in which a heavy frame, carrying the driven friction-wheel, or a weighted bell-crank lever, carrying rollers on the vertical arm is kept out of action by the tension of a chain; these, thrusting apart (when the lever is lowered) disks having inclined planes, "fix" or "loosen" a ratchet-wheel, Fig. 1. The brakes are applied when the tension of the chain is slackened, either purposely or by accident, so that in the one case the driving and driven friction-wheels are brought into contact, and in the

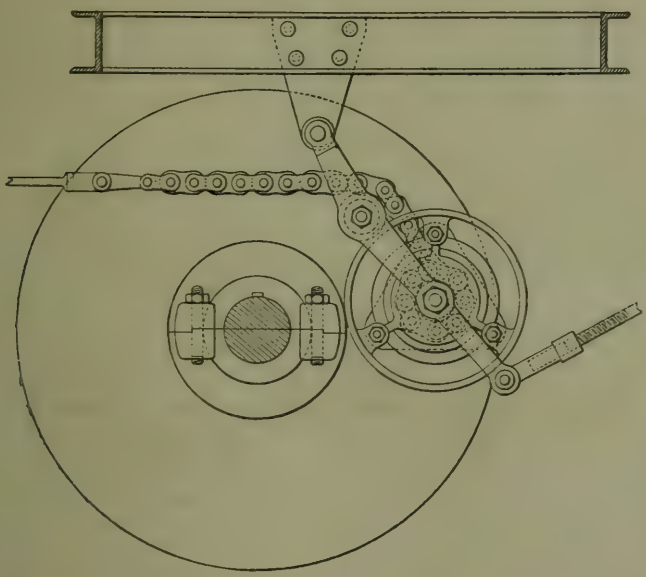
Fig. 1.



other case the ratchet-wheel is fixed, in such a manner, that a part worked by a cam (Wilkin and Clarke's brake) can act on it, the kinetic energy of the train being, in both instances, made to apply the brakes through the rotary motion derived from the van-axle, as shown by Fig. 2. The second method of obtaining automatic action is also followed in those brakes of Class III in which a separate vacuum, or compressed-air reservoir, is used; and in the case of the Barker hydraulic brake a separate accumulator, in which water is stored under the pressure of powerful spiral springs. Communication between these stores of power and the brake-cylinders, where it is applied, is effected by a valve kept in a position of unstable equilibrium when the brakes are off, com-

munication being then closed between the reservoirs and brake-cylinders. This valve shifts its position when equilibrium is disturbed, a communication being opened between the store of potential energy and the brake-cylinders, by which the brakes are applied. The equilibrium of the valve is purposely disturbed by allowing air or water to escape from the brake-pipes, in the case of air and hydraulic-pressure brakes, and in the case of vacuum-brakes by allowing air to enter the train-pipe; the equilibrium of the valve is also disturbed, and the brakes are applied in all three cases, by any accident fracturing the train-pipe or detaching the hose-couplings.

Fig. 2.



As regards the relative merits of the two methods of obtaining automatic action, there is not much to choose between them when applied to brakes of Classes I and II. The first method is more direct, and brake-mechanisms in which it is applied are simpler; at the same time it is worthy of note that the Heberlein, the most successful brake of Class II, is one in which the second method is followed. A comparison between these two methods is, however, unsatisfactory, because brakes of Class I and Class II have been almost entirely superseded by brakes of Class III. It is in brakes of this class, therefore, that the merits and defects of

the two methods of obtaining automatic action are best seen. The first method is exemplified by the differential pressure-brakes of Class III. Its defects, in the case of vacuum-brakes, are that it makes them slow in going "on," because the air which applies the brakes is passed through two valves only, under the most favourable circumstances; and as the brake-cylinders of vacuum-brakes are large, it takes a large volume of air to apply the brakes fully, and as this same volume of air has to be withdrawn through the ejector, the brake is slow in coming off. The action of the brake, when going on, might be quickened by increasing the number of valves for admitting air. Its defects, when applied to high-pressure brakes, are that it is extremely wasteful of air, because a large volume has to be discharged when the brakes are applied, the waste of air varying with the degree of force of the application. It also renders the brake slow in being got off, because the volume of air discharged when applying the brakes has to be recharged by the air-pump, before the former unstable equilibrium of the brake-piston is restored and the brakes thereby released.

The differential air-pressure brakes can, however, be got on more rapidly than the vacuum-brakes, in which this method of working is applied, particularly so where a discharge-valve is applied to each cylinder, as in the Wenger brake. The differential method of working is not applied in any hydraulic brake, but the disadvantages incidental to the method, when used for air-brakes, would be still more apparent in the case of water.

Returning again to the second method of working brakes of Class III automatically, that of using separate reservoirs, with an automatic valve which governs the action of the brake by maintaining or cutting off communication between the reservoirs and brake-cylinders, it does not yield such good results, in the case of vacuum-brakes, as the differential method of working; but it gives the very best results in the case of air-brakes, and it gave good results in the only hydraulic brake, the Barker brake, to which it has been applied.

The principal types of differential pressure brakes are the automatic vacuum-brake, the "Steel and McInnes" air-pressure brake, and the Wenger air-pressure brake,[1] but there are many others. The principal types of separate-reservoir brakes are the "Hardy" automatic vacuum-brake, the Westinghouse automatic-pressure brake, and the "Barker" hydraulic and automatic-pressure brake.

Having dealt with the conditions upon which automatic action

[1] Minutes of Proceedings Inst. C.E. vol. xxviii. p. 389.

depends, the Author will briefly describe a few of the principal types of automatic-brakes of the three classes, references being given to works where full descriptions may be found.

The Clark chain-brake is an example of Class I. In this brake long tension-rods, one rod running on each side of the centre line of the train for its whole length, are connected with the principal levers of the brake-rigging which they actuate. Between the ends of the main levers, and the brackets bolted to the tie-beams of the carriage under-frames, these tension-rods are enveloped by long spiral springs, which are compressed when the tension-rods are pulled, by means of screw-gearing worked by a hand-wheel in the guard's van. If these springs are compressed, before the train starts, they will constitute a store of potential energy, available for direct application of the brakes during the journey when the chains are relaxed, purposely or by the snapping of the tension-rods in case of accident.

This brake (Plate 6, Fig. 1) is an instance of the application of the first method of obtaining automatic action. The Clark (later) chain-brake is an example of Class II. The working of this brake will be easily understood from Plate 6, Fig. 2. It is another instance of the application of the first method of obtaining automatic action; a large amount of potential energy is stored for later application of the brakes, in the vertical springs which are compressed by the winding up of the chain on the drum, when the friction-wheels on the pendulous link and on the van axle are brought into contact.

The Heberlein chain-brake[1] is another example of Class II. It is an instance of the application of the second method of working automatically. A swing-frame, carrying the driven friction-wheel, is held out of action by the tension of a strong line; this passes over guide-rollers, on the roof of the carriages, to the driver's winding-reel, by which he applies or releases the brake.

To bring the brake into action he lets out a certain amount of line; the swing frames, carrying the driven friction-wheels, are thus lowered until they come into contact with the driving-rollers on the axles, when the brakes are applied. The friction-rollers, guide-pulleys, and driver's winding-reel are shown in Plate 6, Figs. 3, 4, and 5.

The Wilkin and Clark chain-brake belongs to Class II. It is another example of the application of the second method for automatically working the brake.

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[1] "The Engineer." Vol. xli. (1886) p. 259.

As in the Heberlein brake, each carriage is supplied with a complete brake-apparatus; a light chain keeps up weighted levers on the carriages, which, when lowered by the slackening of the chain, cause one of the axles on each carriage to develop the power for applying the brakes on the same carriage. A complete illustrated description of this brake is given in Zerah Colburn's work on "Locomotive Engineering." [1]

Colquohoun's brake and Guerin's brake are almost identical; they belong to Class II, and are worked by direct traction from the engine, transmitted through the drawbar to laminated springs.[2] They were designed to meet the contingency of heavy mineral and goods trains getting out of control on a steep bank, and not for the use of passenger trains. Other examples of Class II are mentioned in a list of brakes arranged in their respective classes in the Appendix.

In the vacuum-automatic brake of Class III a combination ejector (Plate 6, Fig. 6) maintains a vacuum, more or less, on both sides of a piston packed with a rolling ring; this piston slides in a cylinder which is placed in a wrought-iron tub, having trunnions to enable it to follow the brake-lever; the top of the cylinder is open to the tub (Plate 6, Fig. 7).

It is evident that when the air has been exhausted from above and below the brake-piston, the piston will be in unstable equilibrium, which any leakage of air to the lower side of the piston will tend to disturb, the brakes being at the same time off. Directly the pressure of air below the piston, acting against the void above, is sufficient to overcome the weight of the piston and levers which help to keep the blocks off the wheels, the piston will begin to rise, and the brakes to be applied with a pressure which increases with the entrance of the air from without. To apply the brakes, the driver admits air to the train-pipe, which by its pressure on the ball in the ball-valve (Plate 6, Fig. 8) seals the vacuum above the piston, which is then pushed up by the pressure of the air, the brakes being thus applied. The same thing happens if a hose-coupling becomes detached, as in the case of a train parting. The brakes are released by the ejector, or, when the carriages are to be shunted and no fitted engine is near, by allowing air to flow to the upper side of the piston, by pulling the cord of the release-valve. This brake is a differential-pressure

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[1] Pp. 305, 306.

[2] "Engineering." Vol. xxxix. (1885) p. 500; and Minutes of Proceedings Inst. C.E. vol. xvii. pp. 153 to 169.

brake. The Steel and McInnes air-pressure brake is also a differential-pressure brake, and belongs to Class III. A pump on the engine forces air along the train-pipe to both sides of the brake-pistons working in the upright carriage cylinders (Plate 6, Fig. 9), equal pressure being maintained on both sides of the piston, so that it is in unstable equilibrium when the brakes are off.

The brakes are applied by discharging air from the pipe and upper ends of the cylinders on the driver opening a valve, or by severing of the train-pipe; the pistons are then pushed up by the pressure of the air below them, the air at high-pressure below and in the enlarged chamber (corresponding to the tub in the last brake) being prevented from escaping by a valve which is closed by the excess of pressure below when the air above it is escaping.[1]

The last brake on the differential-pressure system in Class III is the Wenger brake[2] (Plate 6, Fig. 10). Air from an air-pump passes from it through a controlling piston-valve to the double piston brake-cylinder, the pistons of which are maintained in an unstable equilibrium by the air-pressure between them and in the end divisions of the cylinders. The brakes are applied when air is discharged from the brake-pipe by the driver, or by accidental bursting of a hose-pipe; the pistons in the valves on the brake-cylinders rise, and in so doing uncover an exhaust-port, through which the compressed-air between the brake-pistons escapes, the brakes going on.

As before mentioned, the Wenger brake is much quicker in action than the other brakes on the differential-pressure system because discharge valves are fitted to each cylinder.

The next brakes to be described are those of Class III, in which separate reservoirs and a controlling valve are used to work the brake automatically. In the Hardy automatic vacuum-brake, an ejector on the engine exhausts the air from the train-pipe, the vacuum-reservoir on the engine, and the vacuum-reservoirs on the coaches; in addition to these each coach carries a brake-cylinder whose piston actuates the brake-levers (Plate 6, Figs. 11 and 12). When the brakes are off, communication between the reservoirs and the brake-cylinders is cut off by a double-seated diaphragm-valve, which is maintained in a condition of unstable equilibrium. This is effected by the vacuum in the train-pipe on one side and the vacuum in the reservoir on the other side, a branch pipe from the brake-cylinder leading to the space between the two valve-seats.

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[1] "Continuous Railway-Brakes," by M. Reynolds. 1882.

[2] Minutes of Proceedings Inst. C.E. vol. lxviii. p. 389.

The brakes are applied when air is admitted to the train-pipe, by the driver's valve or by accidental parting of the train-pipe; the diaphragm-valve being then thrown over, and communication opened between the reservoirs and the brake-cylinders, the air from above the brake-pistons exhausts into the reservoirs, falls in pressure, and allows the atmospheric pressure below the brake-pistons to push them up and apply the brakes. It is evident that the degree of force with which the brakes are applied must depend on the degree of rarefaction of the air above the pistons, that is, upon the size of the reservoir, a perfect vacuum being impossible.[1]

In the Westinghouse automatic air-pressure brake, a pump on the engine forces air into a main reservoir under it, and from thence along a continuous train-pipe to auxiliary reservoirs under the carriages; each carriage is likewise provided with a double piston-brake cylinder (Plate 6, Fig. 13). A piston-valve, which is maintained in unstable equilibrium by the pressure in the train-pipe below, and the pressure in the reservoir above it, cuts off communication between the reservoir and the brake-cylinders, the brakes being then off. The brakes are applied when air is discharged from the brake-pipe by the driver, or by bursting of the pipe. The equilibrium of the piston-valve is then destroyed; it falls and opens a passage between the reservoir and the brake-cylinders, the pistons of which are thrust apart and the brakes applied. The brake is released when the equilibrium of the triple valve is restored by admitting air to the train-pipe; the piston then rises and pushes up the D-valve, carried on its spindle into such a position as to cut off communication between the reservoir and the brake-cylinder, at the same time opening the space between the brake-pistons to the exhaust. A graduating valve is introduced into the construction of the D-valve, but it is impossible to describe its construction and action in a few lines. Further information about the Westinghouse brake is given in the Appendix.

In the Barker hydraulic and automatic brake, water is forced by a pump on the engine to an accumulator placed on each coach, where it pushes forward a piston against the pressure of a very powerful spiral spring. A slide-valve carried in the piston (Plate 6, Fig. 14) of the auxiliary piston-valve, is placed in a condition of unstable equilibrium by the pressure of water in the train-pipe on one side, acting against a spiral spring enveloping the piston-valve rod on the other side.

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[1] "Continuous Railway-Brakes," by M. Reynolds. 1882.

When the auxiliary piston-valve is in its normal position of unstable equilibrium, communication between the accumulator and the brake-cylinders is cut off, the brakes being worked directly from the engine force-pump. If, however, the train-pipe should burst, the equilibrium of the auxiliary piston-valve will be disturbed; it will be forced back by the spiral spring, and the little valve it contains will come into such a position as to open communication between the accumulator and the brake-cylinders, the brakes being then applied by the water under pressure from the accumulator, which thrusts out the brake-pistons. For a full description of this brake, the same authority may be consulted as for the last brake.

The advantages of the separate-reservoir system, when applied to air or hydraulic-pressure brakes, are great economy in the use of air and water, and rapidity with which the brakes can be got on and off. As an instance of the economy in the use of air, the Westinghouse [1] brake may be cited, in which a reduction of 20 per cent. in the brake-pipe pressure will bring the triple-valve to the end of its travel, and give the brake-pistons the full benefit of the reservoir-pressure. The great similarity between the brakes, in the typical divisions of Class III, is shown in the following arrangement:—

CLASS III.—AUTOMATIC BRAKES.

1. *Differential-pressure Brakes.*

	Engine-Fittings.	Continuous Coupling.	Carriage-Fittings.	
Name of Brake.	Prime Mover for Exhausting or Compressing Air.	Form of Coupling.	Receptor.	Valve or other Device used for retaining the Vacuum or Compressed Air on one side of the Brake-piston when brakes go on.
Vacuum automatic brake.	Combination ejector.	Train-pipe	Brake-cylinder	Ball-valve.
Steel and McInnes' air-pressure brake.	Air-pumps.	Train-pipe	Brake-cylinder	A valve.
Wenger's air-pressure brake.	Air-pumps.	Train-pipe	Double piston brake-cylinder.	Leather piston packing-rings turned so as to retain the pressure.

[1] "The Engineer." Vol. lxv. (1888) p. 204.

2. *Separate-reservoir Brakes.*

Name of Brake.	Engine-Fittings.	Continuous Coupling.	Carriage-Fittings.		
	Prime Mover for Exhausting Air from, or Compressing it in, Reservoir.	Form of Coupling.	Reservoir.	Valve which controls communication between reservoir and one side of brake-piston.	Receptor.
The Hardy automatic vacuum-brake.	Ejector .	Train-pipe	Vacuum reservoir.	Double-seated diaphragm-valve.	Brake-cylinder.
The Westinghouse automatic-pressure brake.	Air-pumps	Train-pipe	Compressed-air reservoir.	Triple valve	Double piston brake-cylinder.
The Barker hydraulic and automatic brake.	Force-pumps for water.	Train-pipe	Accumulator	Auxiliary piston-valve.	Brake-cylinder.

Concluding Remarks.

From the analysis of brake-mechanisms described, the Author is led to believe that the classification proposed includes them all, being based upon principles of action, and not upon incidental details of design. For this reason he has not described the details of each system as closely as would have been possible, as further details can be obtained without difficulty. A careful study of brake-mechanisms has led him to the following conclusions :—

1. That sectional brakes may be classified according to the form of tool employed in dispersing the kinetic energy of the train, and that continuous brakes must, on the other hand, be classified according to the force available for working the brakes, and the mode of its application to the receptor.

2. That, on this principle, brakes may be placed in three classes, each class containing simple and automatic brakes. That, in countries where a standard gauge is in use on railways, over which mixed trains, made up of rolling-stock of two or three different companies, are run, the advantage of having trains fitted with brake-apparatus, worked on the same principle, and, as far as possible of uniform pattern, is so great, that the present ten-

dency is towards retaining in use only that class of brakes which is designed upon the soundest principle. Further, that as regards the selection of a system from the class retained, that brake will ultimately supersede all others which, in the opinion of railway engineers, best complies with conditions similar to those laid down by the Board of Trade for adoption in this country.

3. That no storage of energy is found in simple brakes.

4. That storing energy is a principle that enters into the design of automatic brakes, and is necessary for the automatic condition to be fulfilled.

5. That brakes of Class III are very closely allied, as shown by a Table in the case of automatic brakes of this class.

6. That the failure of quick leak-off brakes, after their application, is attributable to the fact that the automatic condition is only nominally complied with for a few seconds after the brake has been applied, and that after this the automatic condition is violated.

7. That with reference to the respective merits of vacuum- and of pressure-brakes, it must be borne in mind, as a set-off against the simplicity of the former, that even where a high degree of vacuum is attained, the pressure per square inch for working the brake cannot much exceed, if it is ever equal to, 15 lbs., and that therefore the apparatus of the vacuum-brake is far larger and heavier than that of an air-pressure brake in which high pressures are used, and therefore small parts. By the use of high pressures and small parts for brakes, much quicker action of the brake is gained, as when high-pressure steam is used in high-speed motors. Where, as in the most successful air-pressure brake, separate reservoirs are used in addition to high pressures, the brakes can be got on and off still more rapidly, on account of the economy in the use of air, than where a large volume of air has to be discharged from the cylinder, and again returned to it whenever the brakes are applied or are taken off.

A list of brakes, placed in their respective classes, with references, is given in the Appendix.

Finally, the Author wishes to record his thanks to Mr. A. L. Sacré, Assoc. M. Inst. C.E., to Mr. A. Kapteyn, Assoc. M. Inst. C.E., and to Captain R. Fairholme, for information kindly supplied for the preparation of this Paper.

The Paper is illustrated by numerous diagrams, from which Plate 6 and the Figs. in the text have been prepared.

[Appendix.

APPENDIX.

Simple Continuous Brakes.

Class I.	Class II.	Class III.
The continuous screw-brake, *vide* "Continuous Railway-Brakes," M. Reynolds; also Minutes of Proceedings Inst. C.E. vol. xvii. p. 168.	Clark's original chain-brake, *vide* "Continuous Railway-Brakes." M. Reynolds. The old Heberlein brake.	The Smith vacuum-brake, *vide* "Continuous Railway-Brakes," M. Reynolds. The Hardy simple vacuum-brake, see 'The Engineer,' vol. xlix. p. 291. The Westinghouse vacuum-brake. The Westinghouse simple-pressure brake. The tell-tale vacuum-brake. Kendall's steam brake, 'The Engineer,' vol. xlviii. pp. 270, 272.

Note.—Certain systems can be worked as simple or automatic brakes at the option of the drivers or guards. Where such is the case, a cock is provided in vacuum brakes for cutting off communication between the train-pipe and lower end of the cylinder, and in pressure brakes, the reservoir is cut out of the circuit, the brakes being worked directly from the air-pump.—Minutes of Proceedings Inst. C.E. vol. lxxv. pp. 17 and 18.

AUTOMATIC CONTINUOUS BRAKES.

CLASS I.	CLASS II.	CLASS III.
Clark's No. I chain-brake. "Continuous Railway-Brakes," M. Reynolds.	Clark's No. II chain-brake, "Continuous Railway-Brakes," M. Reynolds. The Barker brake, 'The Engineer,' vol. xlv. pp. 73 and 76. The Guerin brake, Minutes of Proceedings Inst. C.E. vol. xvii. pp. 153 to 169. The Achard brake, 'Railroad Gazette,' vol. i. p. 3; also 'The Engineer,' vol. iii. p. 257. Colquohoun's brake, 'Engineering,' vol. xxxix. p. 493. Wilkin and Clark's brake, "Locomotive Engineering," pp. 305, 306. The Heberlein brake, 'The Engineer,' vol. lxi. p. 259. The Smith friction-brake (earlier pattern), 'The Engineer,' vol. l. p. 421. The Smith friction-brake (later pattern), 'The Engineer,' vol. liv. p. 345. The Wiseman brake, 'The Engineer,' vol. xlviii. p. 73. The Naylor brake, 'Engineering.'	The Aspinall vacuum-brake, see 'The Engineer,' vol. xlviii. pp. 166, 169; also "Continuous Railway-Brakes," M. Reynolds. The Barker Hydraulic brake, 'The Engineer,' vol. xlvii. p. 411; also "Continuous Railway-Brakes," M. Reynolds. The Hardy automatic brake, 'The Engineer,' vol. xlv. pp. 346, 347; also "Continuous Railway-Brakes," M. Reynolds. The Clayton brake (2 minutes lull off). The Eames vacuum-brake, 'The Engineer,' vol. l. pp. 22, 28, 46; also "Continuous Railway-Brakes," M. Reynolds. The Sanders vacuum-brake, 'The Engineer,' vol. xlviii. p. 215; also "Continuous Railway-Brakes," M. Reynolds. The Smith vacuum-brake. The Steel and McInnes brake (air-pressure). "Continuous Railway-Brakes," M. Reynolds. The vacuum-automatic brake, 'The Engineer,' vol. lx. p. 299; 'Engineering,' vol. xxxix. p. 494. The Wenger automatic (air-pressure brake), Minutes of Proceedings Inst. C.E. vol. lxviii. p. 388. The Westinghouse (automatic air-pressure), 'The Engineer,' vol. ix. p. 141; 'Engineering,' vol. xxxix. p. 494; "Continuous Railway-Brakes," M. Reynolds.

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"Boiler-Experiments and Fuel-Economy."[1]

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THE following experiments were made with a view to increasing the efficiency and economy of a certain boiler which had done good work, and had recently been fitted with a grate allowing the use of inferior kinds of fuel. The earlier experiments served to show the saving effected by the use of inferior fuels with the new grate; and these led to further experiments, by which other points affecting the economy of the boiler and flues were arrived at. The grate, an invention of Mr. Perret, of Paris, has been described in a Paper by Mr. W. G. McMillan.[2] The boiler and grate with which these experiments were made are at work at the factory of Messrs. Bryan Donkin and Co., Bermondsey. The boiler (Plate 7, Figs. 1, 2, 3, and 4), of the Lancashire type, by Daniel Adamson and Co., is 7 feet in diameter and 21 feet long, with two circular internal flues each 2 feet 9 inches in diameter; there are three circulating tubes in each flue. The total heating surface is 582 square feet. The boiler, which has an iron shell and steel tubes, is nearly new, and was in a good condition at the time of the experiments. The experiments were carried out by the Author under the direct superintendence of Mr. Bryan Donkin, jun., M. Inst. C.E., to whom he is indebted for permission to make use of them in this Paper.

The leading features of the grate are forced draught and deep water-cooled firebars. The firebars are ranged longitudinally in two lengths (Plate 7, Fig. 1), twenty-six bars in each row; they are about $\frac{5}{8}$ inch thick at the top, tapering down to $\frac{1}{8}$ inch, and lie nearly $\frac{3}{4}$ inch apart from centre to centre, leaving an air-space between each pair of about $\frac{3}{32}$ inch. The grate inclines slightly downwards from the fire-doors; the depth of the first row of bars is 9 inches, and of the second row 8 inches. The ash-pit is

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[1] This Paper was read at a meeting of the Students on the 18th of November 1887.

[2] Journal of the Society of Arts, 1886, vol. xxxiv. p. 532.

closed by an air-tight door, through which passes the pipe which conveys the air to the space below the firebars. The dead-plate extends about 1 foot 6 inches from the fire-doors, and there is a width of 4 or 5 inches of dead-plate along each side of the grate. The total grate area is 7½ square feet in each flue, or 15 square feet in all, exclusive of the dead-plate. In Plate 7, Figs. 1 and 2 show the general arrangement of the grate as applied to the boiler, but with a trough long enough for three instead of two lengths of firebars. The arrangement with three lengths was that first used, but was found larger than necessary. Should, however, more work be required of the boiler a return to the larger grate will be easy. Within the ash-pit a cast-iron water-trough, in which the firebars are immersed in water kept at a constant level by a pipe which passes through the ash-pit door, is connected with a cistern supplied with water from the main controlled by an ordinary ball-cock. The bars dip into the water to a depth of about 3 inches along their entire length, and by this means and by the play of the air around them they are kept at a comparatively low temperature. The bars are ϖ shape, the slot in the web tending to prevent breakage from unequal expansion, and no difficulty is experienced from twisting and its accompaniment of bars displaced. The cooling-action of the water and air on the bars is much greater than might be supposed; for, on pushing back the glowing fuel from the front bars, it is possible to lay the hand where but a moment before a bright fire was burning. This result is not obtained without the loss of some heat to the boiler: but it is more than counterbalanced by the preservation of the bars, which show no signs of wear even after several months. Some bars were recently taken out of one of these grates after twelve months' use, and the foundry marks, even along the tops, were as plain as the day the bars were put in. This feature alone is of considerable importance to many steam-users, who find the frequent failures of firebars a source of continual annoyance and expense. Another advantage arising from the comparatively low temperature of the firebars is the facility with which clinkers can be removed; the surface of the bars being at a temperature below that of the melting point of the clinkers causes the latter to solidify without adhering to the bars; a cake is thus formed which can be easily removed from time to time. The air-blast is obtained by a 22-inch Lloyd's fan, running at about 1,500 to 2,000 revolutions per minute, driven from the shafting in the shop. There is also an alternative method of producing the required air-current by means of a Körting steam injector supplied with high-pressure steam direct from the

boiler (Plate 7, Fig. 4); but the fan alone was employed during the special experiments. The pressure of the air beneath the bars is only about $\frac{1}{2}$ inch of water. In each of the two upright pipes conveying the air to the grates from the main pipe is a throttle-valve, by which the supply to either fire can be adjusted.

The fuels chiefly used with this boiler are: (1) dust-breeze from the gas-works, which, though of low evaporative power, is found to be very economical on account of its low price. (2) Welsh coal-dust, which, although more expensive than breeze, is also economical by reason of its high evaporative power compared with breeze, and its low price compared with lump coal. North country coal cannot be advantageously burned in these grates in London, on account of the quantity of smoke produced. The effect of air-blast with dust fuel, and especially breeze, is to cause a somewhat larger accumulation in the flues of the boiler than would be the case with lump coal; but this is not serious, and for a boiler with fairly large flues working, say, ten hours a day, cleansing every three or four months should be sufficient.

Some idea of the cost of working with this grate and dust fuel may be gained from Tables I and II in the Appendix. Table I shows the average cost of evaporating 1,000 gallons of feed-water from a temperature of about 80° Fahrenheit at a pressure of about 55 lbs. per square inch in each of four months in the year 1885, as well as the quantities of water and fuel consumed.

Table II gives the results of four trials of eleven hours each with different kinds of fuel under similar conditions.

From these figures it appears that the dust-breeze was at the price the most economical; but against that good result must be set off (1) increased labour in stoking, (2) increased labour in attending to fires and removing clinkers, (3) more frequent stoppages for the purpose of cleansing flues, as more of the breeze than of the heavier coal-dust is carried away by the blast. Taking all these points into consideration, it is found that Welsh coal-dust at 9*s*. per ton is as economical as the dust-breeze at 5*s*. per ton.

In some more exact experiments of less duration, attempts were made to ascertain as nearly as possible the evaporative power and efficiency of the boiler and grate with (1) Welsh coal-dust, and (2) dust-breeze, under similar conditions, and also to account as far as possible for the disappearance of the heat supplied to the boiler. The trials took place on the 10th and 12th of March, 1886, on the former day with Welsh coal-dust, and on the latter with dust-breeze; preliminary trials had been also made a few days before. The objects of the trials were mainly two:—

First, by careful measurements of the quantities of fuel and water consumed per hour per square foot of fire-grate and heating surface respectively, to arrive at the efficiency; and by the number of lbs. of water evaporated per lb. of fuel burned, to arrive at the economy of the boiler and grate. Secondly, to discover the total quantity of heat developed in the combustion of the fuel used in the trial, to account as far as possible for the disappearance of the whole of it, and to ascertain the percentages of heat usefully employed and dissipated in various ways in the apparatus.

The fuel to be used was placed conveniently near to the fire-doors in a heap sufficient for the day's consumption, and was carefully spaded over to ensure uniformity of composition. From this heap it was weighed out in quantities of 112 or 160 lbs. in the box of a portable weighing machine, and from thence was served to the fires as required. Two independent records of the number of weighings were taken. The time also at which the last portion of each weighing of fuel was thrown on the fires was recorded, and this gave a rough estimate of the quantity burned in any given period of the day. The number of times of firing each grate was also recorded, with a view of showing the comparative labour for the stoker with each kind of fuel.

The fires were all drawn from the grates at the commencement of the experiment, and 20 lbs. of wood used for relighting. This weight of wood is not included in the results, as it is considered to be more than balanced by the loss of heat from the boiler during the operation of drawing the fires. A record was kept of the times of clinkering or cleansing the fires, and of the quantity of clinker removed at such times. A certain proportion of the fuel drawn from the fires at the end of the trial was assumed to be good, and its weight was deducted from the total fuel supplied. The quantity of moisture in the fuel was ascertained by setting aside a fair sample, say 2 or 3 lbs., in a warm place, having weighed it carefully, and weighing it again when dry, the loss in weight being the amount of moisture in the sample. Selected samples were treated in Thompson's calorimeter to determine the full evaporative power of the fuel; and other weighed samples were thoroughly burned in a crucible to ascertain the proportion of combustible and of incombustible matter in the fuel. The feed-water was measured by a piston water-meter, Kennedy's patent, which had been checked against a tank of known capacity, and the errors of the meter thus found have been allowed for in the results. The number of gallons recorded by the meter were entered at the commencement and close of the experiment. The

water-level in the boiler was kept constant as nearly as possible at a mark made on the gauge-glass at the commencement of the experiment. Readings of the meter and of the water-level at the end of every hour gave the consumption in that interval.

The steam-pressure was observed by a Bourdon gauge previously compared with a column of mercury, and the slight necessary correction is considered in the pressures recorded.

The results of the observations described above will be found in the Appendix, Table IV, column 1, showing the performance of the boiler and grate with the coal-dust, and Table IV, column 2, the same with the dust-breeze. Besides these operations, attempts were made to account as far as possible for the disappearance of all the heat supplied to the boiler. It is evident that, in addition to a knowledge of the quantities of fuel burned and feed-water evaporated in a given time, there must also be known (1) the full calorific power of the fuel; (2) the temperature from which the feed-water was raised, and that at which it was evaporated; (3) the temperature at which the air supplied for combustion entered the grate, the volume that so entered, and the temperature of the issuing gases as they left the boiler; (4) the percentage chemical composition of the fuel and of the gases as they left the boiler.

Taking these various items in the order given, the calorific power of the fuel is most easily found by Thompson's calorimeter, the results being expressed in the number of units of water that can be converted into steam from and at 212° Fahrenheit per unit of fuel.

On the debit side of the balance-sheet the most important item is the amount of heat usefully absorbed in the evaporation of the water supplied to the boiler. The average temperature of the feed-water as it enters the boiler is ascertained by a thermometer, and from the readings of the steam-pressure gauge the temperature of the steam leaving the boiler can easily be found, or what is more to the point, its total heat above that of the entering feed-water. This of course includes the latent heat of steam, and, when multiplied by the weight of water evaporated during the trial, gives the number of thermal units that have been usefully employed in the work of steam-producing. The percentage of this figure of the whole number of thermal units supplied to the boiler gives a very fair idea of the efficient working of the grate and flues and of the boiler itself.

The next important item on the debit side of the sheet is the heat carried away and dissipated by the issuing furnace-gases;

and to arrive at the amount thus lost the chemical composition of the gases as they leave the boiler must be known, their bulk and their temperature at the same point, as well as the temperature of the air supplied to the fires. From a knowledge of these points it will be known whether the right amount of air for the quantity of fuel being burned is being admitted, so as to get not only complete combustion but also the largest percentage of the heat evolved by the fuel absorbed in the production of steam. In the recorded trials two methods were employed with this view: (1) Volumetric analyses by Bünte's burette of samples of the gases drawn from the chimney; and (2) the calculation of the quantities of each gas that would result from the combustion of the fuel with the air supplied.

As the second method of determining the chemical composition of the issuing gases depends more on calculation than on observation, it may possibly fail to find favour with those who advocate practice as opposed to theory; but the method shows what sort of results may be expected with fuel of a certain quality, and also under what conditions it should be used. But it has the disadvantage that it depends on the possession of an accurate chemical analysis of the fuel, and this is not always within the reach of boiler-owners. In the case under consideration reliance was placed on an analysis by Dr. Percy, Hon. M. Inst. C.E., some years ago, of coal from the same colliery. The coal was Welsh dust, Nixon's Navigation, and, though it was apparently bright and clean, it probably contained more dirt and so less combustible matter than Dr. Percy's sample.

Table III in the Appendix gives the composition of the coal, and the amounts of the different elements in the day's charge.

The analyses by Bünte's burette showed, by the absence of carbonic oxide, that the whole of the carbon was thoroughly burned, and from this it may be safely assumed that the hydrogen and sulphur were also.

The quantity of air entering the grates was measured by a Lownes' anemometer. A door was provided for it in the air-supply pipe at the front of the boiler, and the area of the square pipe was reduced for a short distance to a circle about 7 inches in diameter, so that the free area through and round the anemometer when in position was 0·296 square foot. Readings of the velocity of the air and of its temperature were taken at intervals during the day, and the mean velocity was found to be 2,248 feet per minute at a mean temperature of 58° Fahrenheit, at which temperature the weight of 1 cubic foot of air is 0·076 lb. The duration of

the experiment was eleven hours; so, the total weight of air supplied to the fuel was 2,248 feet per minute × 0·297 square foot × 0·0767 lb. × 60 min. × 11 hours = 33,798 lbs. Now the carbon in the day's charge took up $\frac{1,892 \times 32}{12} = 5,045$ lbs. of oxygen, and formed 6,937 lbs. of carbonic acid gas; the hydrogen took up $\frac{102 \times 16}{2} = 816$ lbs. of oxygen, to form 918 lbs. of water, and the sulphur took up $\frac{13 \times 32}{32} = 13$ lbs. of oxygen, and formed 26 lbs. of sulphur dioxide. Thus the total weight of oxygen required for the perfect combustion of the fuel was:—

For the carbon	5,045 lbs.	of oxygen.
„ hydrogen	816	„ „
„ sulphur	13	„ „
„ day's coal	5,874	„ „

But the charge of coal itself contained 48 lbs. of oxygen; hence the oxygen required from the air supplied was 5,874 − 48 = 5,826 lbs.; whilst the air actually supplied contained $\frac{33,798 \times 23}{100} =$ 7,773·5 lbs. of oxygen, on the assumption that air contains twenty-three parts by weight of oxygen in one hundred parts. Deducting the quantity required for combustion, viz., 5,826 lbs., the excess of oxygen supplied was 1,947·5 lbs., and this is equivalent to 8,467 lbs. of air; whilst the nitrogen which was present with the air was 10,504 lbs. Therefore the weights of the various gases that passed through the flues and escaped up the chimney at a mean temperature of 376°·5 Fahrenheit were:—

	Lbs.
Excess air	8,467
Nitrogen of utilized air	19,504
Carbonic acid gas	6,937
Water by combustion of hydrogen	918
Hygroscopic moisture in coal	93
Water evaporated from troughs	416
Total	36,335

The amount of water evaporated from the troughs was ascertained by shutting off the usual supply through the ball-cock, and measuring the quantities supplied by hand required to maintain a constant level through a given interval; the mean of several experiments has shown the quantity evaporated from the two

troughs to be 2·6 per cent. of that evaporated in the boiler in the same time.

Thus far the quantities of the various gases leaving the boiler have been ascertained, and also their mean temperature, but not the amount of heat carried off by them individually and collectively. This, of course, depends on the specific heat of the different products of combustion.

In this particular experiment, where the mean temperature of the entering gases was 58° Fahrenheit, and of the issuing gases 376°·5, the loss to the boiler corresponded to a rise of 318°·5; and taking their specific heat into consideration it will be found that the heat dissipated by the various issuing gases was:—

	Thermal units.
Excess air	641,823
Nitrogen	1,515,729
Carbonic acid	478,122
Water from hydrogen in coal	1,101,272
Moisture in coal	113,966
Evaporation from troughs	498,219
Total	4,349,131

These figures give a fair general idea of the large amount of heat wasted in the furnace gases; but as the first of these is the only one which can be reduced by careful management, it is on that account the most important. Theoretically there should be no excess air, but since an insufficient air-supply would result in a far more serious loss of heat, on account of the production of carbonic oxide instead of carbonic acid gas, it is always necessary to have a margin of safety on the side of too much rather than too little oxygen. In this particular case, the calculated result shows a ratio of air supplied to that theoretically required of 1·3 to 1; but as the measurement of the volume of air was at the best but an approximation, it is possible that the true ratio may be higher. It is difficult to say by how much this ratio might be safely reduced, and it is a point of great importance to designers of furnaces, as on it depends the amount of opening between the bars, and in the case of grates for forced draught the size of the air-supply pipes also. These figures also show how large a portion of the heat is carried off by the nitrogen of the air, which, although it has not in any way increased the total, dissipates a far larger amount of heat than the carbonic acid, in the production of which so much heat was evolved. The water produced by the combustion of the hydrogen in the coal is accredited with much of the

loss, and by this the high calorific power of hydrogen compared to that of carbon (34,460 to 8,080) is considerably neutralized.

The moisture from the coal, and that, in this special case, evaporated from the troughs, are both heated up at the expense of the fuel, and give out no heat in return; and, since also both are converted from water into steam and so dispersed, the large quantity of heat become latent is lost to the boiler. The temperature of these issuing gases was observed by a mercurial thermometer, which gives fairly accurate results up to 500° Fahrenheit, hung in the centre of the chimney, and observed through an aperature, fitted with a pane of glass in the side of the chimney, illumination being obtained by the reflected light of a gas jet outside. Readings were taken at the rate of at least one every fifteen minutes, and frequently at much shorter intervals. The following points were noticed: (1) a sudden fall in temperature attending a discontinuance of the blast; (2) a higher temperature in the chimney with the steam jet than with the fan blast; (3) a sudden rise and subsequent fall in the temperature when the fire-doors were opened for a short period.

For taking the temperatures of the flues, and other places, a weight pyrometer or calorimeter was used.

Since these experiments were made, a piece of apparatus has been arranged, by which a continuous sample of the issuing gases is drawn from the chimney and absorbed in various weighed reagents throughout the experiment. This apparatus has given very good results when used for so long a period as eight hours.

The next item in the balance-sheet is the heat lost by radiation or cooling, which in this case was arrived at by the following very rough experiment. After the day's work the fires were all drawn from the grates; the fire-doors, damper, and all steam and feed valves were carefully closed, and the boiler was left to itself for some hours. Readings of the steam-pressure and of the water-level were made at the commencement and at intervals during the experiment, which was continued till the steam-pressure had fallen to about 20 lbs. per square inch by the gauge. With a certain water-level the capacity of the steam and water spaces respectively were known, and from this and the temperature of the steam at the recorded pressures the number of thermal units present in the water, steam and metal of the boiler, both at the commencement and close of the experiment, were obtained. The deficiency of the latter from the former shows the loss of heat during the experiment. Such an experiment can be regarded as only of comparative value; the most evident fault is that as the pressure of steam

in the boiler fell, the amount of heat radiated would be less, and consequently the result obtained would be less than the truth for the whole day's trial. Another difficulty arises from the practical impossibility of carrying out a second experiment under precisely the same atmospheric conditions as in a previous one. The value given in the balance-sheet, 133,647 thermal units lost per hour, was obtained from an experiment made a few days after the main trials, under approximately similar conditions, and agrees fairly well with several others made about the same time.

A better method than the above seems to be in contracting very considerably the area of the fire-grate, carefully closing all steam and feed-pipes, and maintaining the ordinary working steam-pressure by a small fire of the same sort of coal as that used in the main trial. Such experiment should be of not less that six hours duration; and the volume and temperature of the entering and issuing gases should be observed as well as the quantity of coal or other fuel burned.

It will be found impossible, under the various items mentioned above, to account for all the heat given out by the fuel, and placed on the credit side of the balance-sheet; so, on the debit side, under the head of unaccounted for, are grouped the various undetermined quantities, which have either been neglected altogether, or under-valued in their proper place, and which go to make the debit side balance with the credit. With a little trouble some of these amounts may be roughly estimated, such as the heat in the burning fuel when it is drawn from the fires at the close of the experiment, and in the ashes and clinkers removed from the fires during the day. Amongst the remaining quantities of heat lost, solid carbon and imperfectly burned hydrocarbons in the smoke may be included, also heat lost by leakage of cold air into the flues, and unburned carbon amongst the ashes and clinkers.

The percentages of the different items of heat absorbed of the total quantity evolved will be found between the columns of the balance-sheet of heat evolved and heat absorbed; these figures show the performance of the boiler, and afford a ready means of comparison with the results, similarly expressed, of other boiler-trials working under the same or under different conditions. As has been already pointed out, the best performance will be that in which the first item—the evaporation—is the highest, and the third and fourth, the radiation and "unaccounted for," are the lowest; whilst the second item should also be low, provided that carbonic oxide is absent from the issuing gases. Such a system of balance-sheet seems to the Author to be the most

convenient and useful form in which the performance of a steam-boiler can be expressed; and were such a balance-sheet presented in conjunction with a careful estimate of the quantities of fuel and water expended, and other results, such as those indicated in the earlier portion of this Paper, it would form a not unfitting accompaniment to some of the elaborate steam-power trials published from time to time, but which are marred by the pre-eminence given to the motor over the producer.

Since carrying out the foregoing experiments, the Author has had the opportunity of assisting in another experiment, in which precautions were taken to avoid errors possibly existing in the results before recorded; and as this experiment is consequently of more value than the former ones, the details of it are given (Appendix, Tables VII and VIII).

The improvements in the methods of observation were :—

(1) The feed-water was measured in a carefully gauged tank instead of by a water-meter.

(2) The anemometer for measuring the velocity of the air-supply was placed in such a position, that the whole of the air passed through the instrument, instead of partly round it and partly through it.

(3) The coal was specially analyzed.

(4) The heat value of the coal was determined by an improved Thompson's calorimeter, and carefully compared with fuel of known heating power.

(5) The temperature of the issuing gases was observed at a point much nearer to the damper than in the previous trials.

(6) The chemical composition of the issuing gases was determined by the continuous apparatus previously referred to, and from this analysis the volumes of the various gases leaving the boiler were determined, instead of from the volume of air entering the grates as measured by the anemometer.

By comparing the result of this experiment with the earlier ones, it appears that in the experiments in 1886, the heat-values of the fuels, and the volumes and temperatures of the issuing gases, were probably under, rather than over estimated.

In this experiment, the continuous analysis apparatus was arranged, so that the sample was drawn through an iron pipe passing down to within 6 inches of the bottom of the flue in front of the damper, about 3 inches from it on the boiler side. Gas was drawn continuously for seven hours and three-quarters, in which time 6·308 gallons of water were run out from the aspirator, and

as the moisture and carbonic acid gas were absorbed by the reagents in the bulbs, it follows that there were 6·308 gallons of nitrogen, oxygen, and possibly carbonic oxide in the aspirator at a temperature of 82° Fahrenheit, and at a vacuum of 12·5 inches of water, the barometer standing at 30·3 inches. Analysis of these residual gases, by the Bünte burette, showed their composition to be by volume CO_2, 0·0 per cent., O, 11·5 per cent., CO, 0·0 per cent., and N (by difference), 88·5 per cent. The increase in weight of the moisture-absorbing bulbs was 1·174 gram, and in the carbonic-acid absorbing bulbs 4·806 grams. The weights of oxygen and nitrogen respectively in the residual gases were thus determined, all quantities for convenience being taken according to the metric system and Centigrade scale of temperature:—

6·308 gallons = 28·643 litres, subject to correction for temperature and pressure.

Correction for pressure (760 millimetres of mercury), 12·5 inches of water = 0·9 inch of mercury, 30·3 − 0·9 = 29·4 inches = 746·76 millimetres.

$$\frac{28\cdot643 \times 746\cdot76}{760} = 28\cdot144 \text{ litres at standard pressure.}$$

Correction for temperature 0° C. 82° Fahrenheit = 28° Centigrade.

$$\frac{28\cdot144 \times 273}{273 + 28} = 25\cdot526 \text{ litres at 0° Centigrade and 760 millimetres pressure, of which 11·5 per cent. was oxygen and 88·5 per cent. nitrogen.}$$

The weight of 1 litre of oxygen at 0° C. and 760 millimetres pressure = 1·43 gram.
" 1 " nitrogen " " = 1·256 "

	Litres.	Grams.	Per cent.
Therefore	O = 25·526 × 0·115 × 1·43	= 4·197 grams	= 10·88 of O
	N = 25·526 × 0·885 × 1·256	= 28·373 "	= 73·61 " N
	CO_2 = by direct measurement	4·806 "	= 12·46 " CO_2
	H_2O = " "	1·174 "	= 3·05 " H_2O

In order to reduce these percentages to actual quantities representing the total weight of each gas produced during the experiment, the amount of any one of them must first be determined. The carbonic acid gas is the most suitable for this purpose; for from the analysis of the coal, the amount of carbon, and, consequently, the weight of CO_2 that would be produced in the combustion of a given weight of coal, are known; from this it follows that 4,061 lbs. of CO_2 were produced during the nine hours, and since 12·46 per cent. corresponds to 4,061 lbs. the other quantities are:—

	Per cent.		
CO_2	= 12·46	= 4,061	lbs.
O	= 10·88	= 3,480	,,
N	= 73·61	= 23,687	,,
H_2O	= 3·05	= 999	,,

All of which entered the grates at a temperature of 65°·5 Fahrenheit, and left the boiler at 399°, a difference of 333°·5 Fahrenheit, which represents a loss of heat to the boiler of 3,667,000 British thermal units.

Thus—

	British Thermal units.
CO_2	293,000
O	254,000
N	1,928,000
H_2O	1,192,000
	3,667,000

Radiation in this case was measured by the quantity of the same coal required to keep up a constant steam-pressure during nine hours, when no steam was taken from the boiler.

The balance-sheet, Table VIII, is given in thermal units per single lb. of pure and dry coal, the quantities being thus more easily realized for 1 lb. than for the whole day's charge; also, by estimating, for pure and dry coal, errors arising from differences in the amounts of ash and moisture in different samples are eliminated.

The result shows a fairly good economy for a cold feed, but the item 10·5 per cent. unaccounted for shows a considerable margin still left for further research.

In conclusion, the Author desires to express his thanks to Messrs. Bryan Donkin and Co. for the facilities they have given him in the preparation of this Paper.

The Paper is accompanied by several diagrams, from which Plate 7 has been engraved.

APPENDIX.

TABLE I.—RECORD OF WORK WITH PERRET'S GRATE, AND COST OF, AS COMPARED WITH ORDINARY GRATE.

1885.	Water Evaporated.	Breeze Burned.	Cost of Breeze.	Perret's Grate.	Ordinary grate, large coke, in 1884.
				Cost of Evaporating 1,000 Gallons of Water.	
	Gallons.	Lbs.	£. s. d.	s. d.	s. d.
July	26,910	59,496	7 3 0	5 $3\frac{3}{4}$	11 9
August . . .	27,050	60,246	6 13 $9\frac{1}{2}$	4 $11\frac{3}{4}$	12 7
September . .	24,960	56,625	6 13 9	5 $4\frac{1}{2}$	14 8
November . .	38,670	86,366	9 18 $5\frac{1}{2}$	5 $1\frac{1}{2}$	13 8

The price of the breeze varied from time to time.

TABLE II.—PERRET'S GRATE WITH VARIOUS FUELS.

Kind of fuel.	Fuel Burned.	Water Evaporated.	Lbs. of Water per lb. of Fuel.	Cost of Evaporating 1,000 gallons.
	Lbs.	Lbs.		s. d.
1. Dust-breeze . . .	2,800	14,300	5·1	4 $4\frac{1}{2}$
2. Dust-breeze 1 part / Dust-coal 1 part .	3,008	17,400	5·8	5 9
3. Dust-coal	2,016	15,300	7·6	5 $10\frac{1}{2}$
4. Welsh coal-dust . .	2,231	15,820	7·1	6 $3\frac{1}{2}$

TABLE III.—ANALYSIS OF COAL AND QUANTITIES BURNED.

	Per cent.	lbs.	
Carbon . .	84·79	or 1,892	in the day's charge of 2,231 lbs.
Hydrogen .	4·55	,, 102	,, ,, ,,
Oxygen . .	2·17	,, 48	,, ,, ,,
Nitrogen . .	0·96	,, 21	,, ,, ,,
Sulphur . .	0·57	,, 13	,, ,, ,,
Ash . . .	2·79	,, 62	,, ,, ,,
Water . .	4·17	,, 93	,, ,, ,,
	100·00	2,231	

TABLE IV.—RESULTS OF EXPERIMENTS. 1886.

	Coal-Dust.	Coke-Dust.
Date	March 10	March 12
Duration of experiment . . . . . hours	11	13·25
Mean pressure of blast below firebars . inches of water	0·5	0·4
„ temperature of air entering grate . ° Fahrenheit	58	58
„ „ issuing gases . . . „	376·5	399·5
„ pressure of steam in boiler by Bourdon gauge . . . . lbs. per square inch	46·2	44
Fuel.		
Price delivered into boiler-house per ton . . . . *s.*	10	5
Weight of 1 cubic foot . . . . . lbs.	..	33·5
Percentage of moisture in fuel	4·17	3·12
Burnt, not deducting moisture . . . . . lbs.	2,231	3,360
„ per hour . . . . . „	202·8	253·6
„ „ per square foot of fire-grate	13·5	16·9
„ „ „ „ heating surface . . .	0·35	0·43
Ashes . 58 lbs. 68 lbs. Clinkers 176 „ 595 „ Total 234 „ from coal 663 „ from coke } per cent.	10·5	19·7
Weight of air per lb. of fuel . . . . . lbs.	14·37	12·1
Mean thickness of fuel on grates . . . . inches	5	4
Each fire stoked per hour . . . . . times	2·5	4
Water.		
Mean temperature of feed . . . . . ° Fahrenheit	92·9	89·3
Evaporated in boiler . . . . . lbs.	15,820	17,580
„ per hour . . . . . „	1,438	1,326
„ „ per square foot of fire-grate . „	95	88
„ „ „ „ heat surface „	2·5	2·3
„ per lb. of fuel burned . . . . . „	7·09	5·23
„ „ „ from and at 212° F. „	8·14	6·02
„ from troughs . . . . . „	416	462

TABLE V.—BALANCE-SHEET OF HEAT-UNITS FOR BOILER-TRIAL WITH COAL-DUST.

Heat Evolved.			Heat Absorbed.	
Cr.	Heat-Units.	Per cent.	*Dr.*	Heat-Units.
Heat value of coal burned during trial . . .	27,585,869	63·7	Feed-water evaporated . . .	17,560,200
		15·8	Furnace gases .	4,349,131
		5·3	Radiation . . .	1,470,117
		15·2	Unaccounted for .	4,206,421
Total . .	27,585,869	100·0	Total . .	27,585,869

TABLE VI.—BALANCE-SHEET OF HEAT-UNITS FOR BOILER-TRIAL WITH COKE-DUST.

Heat Evolved.			Heat Absorbed.	
Cr.	Heat-Units.	Per cent.	*Dr.*	Heat-Units.
Heat value of coke-dust burned during trial .	28,238,112	69·3	Feed-water evaporated . .	19,568,298
		14·8	Furnace gases .	4,179,874
		6·3	Radiation . . .	1,770,823
		9·6	Unaccounted for .	2,719,117
Total . .	28,238,112	100·0	Total . .	28,238,112

TABLE VII.—TRIAL WITH COAL-DUST, January 14, 1887.

Duration of experiment	hours	9
Mean pressure of blast below firebars .	inch of water	0·1
„ temperature of air entering grates, thirty-three observations . .	° F.	655
„ temperature of issuing gases, one hundred and eight observations	„	399
„ pressure of steam in boiler by self-recording gauge . . .	lbs. per square inch	50
Air required for combustion of 1 lb. of the coal .	lbs.	11·7
Air supplied per lb. of coal burned, by anemometer	„	13·18

Fuel.

Dust from Nixon's navigation (Welsh) coal. Analyis of coal—sample freed from moisture—C, 88·58; H, 4·10; O, 2·76; S, 0·66; N, 1·00; ash, 2·90 per cent.		
Heating power, by calorimeter, for pure and dry coal	Th. U.	16,734
Moisture in coal as used	per cent.	5·5
Total fuel used, including ashes, clinkers, and moisture	lbs.	1,387·5
Ashes, 76·5 lbs.; clinkers, 21 lbs.		97·5
Mean thickness of fuel on grates	inches	8·5
Analysis of issuing gases taken continuously. Percentages by weight, CO_2, 12·46; CO, 0·0; H_2O, 3·04; O, 10·89; N, 73·61.		

Water.

Mean temperature of feed, forty observations . .	° F.	48·6
Total water evaporated in nine hours, measured in tank	lbs.	11,497
Water evaporated per hour	„	1,277
„ „ „ per square foot of heating surface . . .	„	2·4
„ „ „ lb. of fuel from temperature of 48°·6 F.	„	8·3
„ „ „ lb. of fuel from and at 212° F.	„	9·96

TABLE VIII.—BALANCE-SHEET OF HEAT-UNITS FOR TRIAL WITH WELSH COAL-DUST. PER LB. OF PURE AND DRY COAL.

Heat Evolved.		Heat Absorbed.		
Cr.	Heat-Units.	Per cent.	*Dr.*	Heat-Units.
Calorimetric value of 1 lb. of coal pure and dry .	16,734	65·9	Feed-water evaporated . . .	11,026
		18·2	Issuing gases . .	3,040
		4·7	Radiation . . .	790
		0·7	Ashes and clinkers, &c. . . .	117
		10·5	Unaccounted for .	1,761
Total . .	16,734	100·0	Total . .	16,734

(Students' Paper No. 230.)

"River-Gauging at the Vyrnwy Reservoir."[1]

By JOHN HENRY PARKIN, Stud. Inst. C.E.

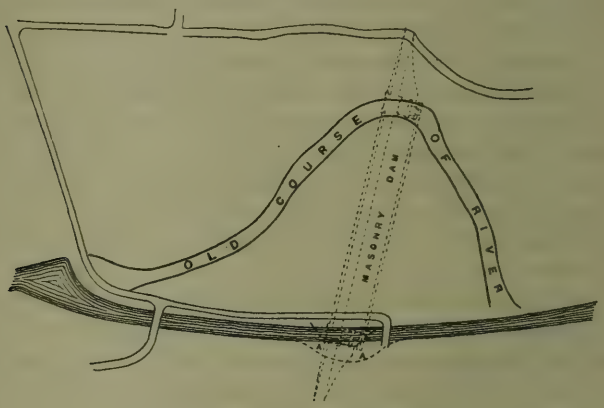
THE gauging-operations which form the subject of the present communication were to determine the daily discharge of the River Vyrnwy past the site of the Vyrnwy masonry dam now in course of construction. This dam will, when completed, impound the waters of the Upper Vyrnwy, and form a lake nearly five miles long, having an area of 1,165 acres, and containing about 12,000,000,000 gallons. The water thus impounded is to supply Liverpool, as the existing water-supply of that city will soon be inadequate to meet the demands of the rapidly increasing population. The Vyrnwy, which is a tributary of the Severn, takes it rise on the Berwyn Hills, at the junction of the counties of Montgomery and Merioneth. After a rather rapid descent for about three miles, the river enters a long flat valley, where it is joined by several smaller streams, and flows with very little velocity for about four miles, until within a few hundred yards of the masonry dam. Before the works for the construction of the dam were commenced, the course of the stream was round a sharp bend. This was not at all favourable to a rapid discharge, as was amply proved in times of heavy rains when the valley was flooded for a very considerable area above the site of the works. For this, and for other reasons connected with the works, the river was diverted to a new channel (Fig. 1, p. 354), which commenced 270 yards above the masonry dam, and had a very gentle sweep in its course, till within 50 feet of the gauging-section (which was 150 yards below the dam), when it became straight. The bed and banks were pitched with stone. The width of the bed was 33 feet, and the banks were sloped 2 to 1, the longitudinal inclination being 1 in 200. For the gauging-operations, a further length of 100 feet was lined with cement concrete rendered with cement mortar, the concrete only extending 2 feet

[1] This Paper was read at a meeting of the Students on the 16th of December, 1887.

up the slopes, with the exception of 20 feet at the centre of the 100-foot length, where it extended to the top of the banks. This concrete lining reduced the width of the bed from 33 to 32 feet, and raised it 6 inches above the original level of the channel. The up-stream end of the concrete was sloped down at 1 in 8 to join the lower level, whilst at the down-stream end, an abrupt enlargement was made to the original size of the channel. At a distance of 80 feet further down the stream, a 20-foot rectangular notch was fixed to gauge very small quantities.

The velocity of the stream was generally determined by an electric current-meter, of the type designed by Mr. G. F. Deacon, M. Inst. C.E.[1]

FIG. 1.



To gauge the direct forward velocity with a current-meter, the vanes of the meter must lie in a plane at right-angles to the axis of the channel; and to obtain accurately the average velocity at any point, the meter must be stationary during the observation. These requirements were practically obtained in the Vyrnwy gaugings. With regard to the above requirements, Professor Unwin has shown,[2] that if the meter were at an angle of 20° with the normal to the section, there would be an error of 6 per cent. in the velocity observed, and if it swung backwards and forwards through an angle of 40°, the error would be only 3 per cent. In the Vyrnwy, at the gauging-section, there was a considerable

[1] Minutes of Proceedings Inst. C.E. vol. lxix. p. 397.
[2] *Ibid.* vol. lxxi. p. 40.

deflection of the current, from the left or north-west bank towards the centre of the stream, and the deflection being always in the same direction, the tendency was to keep the meter inclined at a very large angle to the normal to the section, in which position the error would have been very great, so that it became necessary to fix the meter rigidly, to ascertain accurately the direct forward velocity. At the centre of the cement reach, a bridge was constructed across the channel at right-angles to its axis, the top of the bridge being 11·25 feet above the bed of the stream. The bridge was formed of two trussed wooden girders 1 foot 4 inches deep and 6 inches wide, set 1 foot 6 inches apart (Plate 8, Figs. 2 and 4).

The floor of the bridge was of $\frac{3}{4}$-inch boards laid diagonally on the top of the girders, the whole structure being stiffened by $\frac{3}{4}$-inch iron bolts, at distances of 13 feet, connecting the two girders together. Two strips of iron $\frac{1}{2}$ inch by $\frac{1}{4}$ inch, were laid on the flooring-boards for the whole length of the bridge, one strip on each side, which served the purpose of rails, on which ran the carriage carrying the meter.

On the down-stream side of the bridge was a hand-rail, on which were marked consecutive numbers 1 foot apart, for the purpose of indicating the horizontal position of the meter during an observation.

For placing the meter at the different positions in the stream, a carriage of the following description was used (Plate 8, Fig. 3). It consisted of a triangular wooden bed-plate A B C supported on three rollers, one at each corner, the apex of the bed-plate being on the down-stream side of the bridge, and the side subtending it being flush with the up-stream side. The rollers ran on the longitudinal iron strips previously described. From the bed-plate rose two hollow wooden posts, D E and C F, of V section, and connected together at a height of 14 feet by the cross-piece E F. The post C F was set up at the apex of the triangular bed-plate, and the one D E at the centre of the opposite side A B, so that the side A B being parallel to the centre line of the bridge, the cross-piece E F would be parallel to the axis of the stream. The bar G H, to which the meter was attached, was of iron of a fish-back section, and slid in the guide I I, in which it could be raised or lowered by means of a wire-rope passing over small pulleys at E and F, one end of the rope being attached to the bar, and the other to a counterweight K, slipping in the hollow post C F. Near the bottom of the bar, on the up-stream side, was a projecting spindle turned down parallel to the bar, the bottom

of the spindle being a little above the bottom of the bar. To this spindle the meter was attached. The counterweight was not quite so heavy as the bar, so that a little force was necessary to raise the bar, which, when removed, would allow it to fall again by its own weight. To raise the bar and to adjust the meter nicely to any depth of water, a rope was carried from the bottom of the weight, under the pulley M, and wound on the drum N, by turning which the meter could be raised. A ratchet and pawl attached to the spindle of the drum, allowed it to be fixed so as to maintain the meter at any required depth. The meter was adjusted horizontally by moving the carriage along the bridge, by means of the endless wire-rope O O passing round a pulley P at one end of the bridge, and round the drum Q at the other, by turning which, in one direction or the other, the carriage could be propelled either way along the bridge, the rollers under the bed-plate serving to keep its motion parallel to the centre line of the bridge.

To prevent vibrations in the bar when immersed in the stream, or its bending owing to any deflection of the current, two ties of pianoforte-wire were attached to the bar near the bottom, one wire on each side, and passed round pulleys set in the ends of a wooden bar $6\frac{1}{2}$ inches by $4\frac{1}{2}$ inches, extending 8 feet 3 inches each side of the centre of the carriage. The bar was stiffened by $\frac{3}{4}$-inch iron rods and wooden struts (Plate 8, Fig. 2). The wires, after passing round the pulleys, were wound round a drum U, fixed on the carriage, by means of which they could be tightened simultaneously for varying depths of the meter, a clamp at X preventing the tension of the wires from raising the bar. Thus, the bar was prevented from vertical movement by the clamp, from horizontal movement in one direction by the tension of the wires, and in another by the guide in which it slid, thus securing rigidity.

To prevent the carriage from canting over on the up-stream side of the bridge, owing to anything striking the bar when in the water, a wooden beam was placed at the back of the bridge, against the bottom of which the top of the roller at the back part of the carriage, was just in contact. The electrical connections were earth to bell, bell to battery, battery to instrument, all insulated. The earth wire from the instrument was connected with the wire-strand which gave horizontal motion to the carriage.

The operations were carried out thus:—An observer read the level of the water as shown on two staffs, laid in the banks of the river, on one each side near the line of the gauging-section.

These staffs were graduated to record the vertical height of the stream in feet and decimals of a foot, the zero of the staffs being set level with the bed of the gauging-section. The level of the water and the time were noted, and the carriage was run out to the nearest station immediately under which there was sufficient water to immerse the meter. The number of the station, shown by the position of the carriage with reference to the numbers marked on the hand-rail, was also noted. Then the bar with the meter attached was lowered till it rested on the bed of the stream, when it was clamped, and the tie-wires were tightened. The observer in the hut then recorded with a stop-watch the time between four rings of the bell, which corresponded with 80 revolutions of the vane of the meter. Several time-observations were made before moving the meter (the least being three which corresponded to 240 revolutions of the vane), and the mean of these was taken as the mean time for 80 revolutions at that point. The bar was then unclamped, the meter raised out of the water, and the carriage moved forward 2 feet. The bar was again lowered to the bed, clamped, and readings were taken as before. Then the bar was raised, and other readings were taken, the vertical distance between consecutive readings depending on the level of the water, and the position of the vertical section. On the slope, it was generally every 3 inches, on the bed every 6 inches, in each case with a reading just sufficiently below the surface to immerse the meter. In shallow water the vertical distance between consecutive readings was much less than in deeper water.

The vertical sections were generally 2 feet apart, sometimes being taken somewhat closer on the slopes. The water-level at the staffs was constantly observed during the observations. The manner of entering the observations is shown in the following example (p. 358):—

The least discharge that could be gauged by the current-meter was where there was only 4 inches depth of water flowing in the channel. Weeds and leaves adhering to the vanes of the meter were an objection, but by taking the observations shortly after the flood had attained its crest this inconvenience was very much diminished. Very little difficulty was experienced in this respect in the Vyrnwy gaugings.

The wind, whether blowing up or down stream, had little apparent effect except on the surface velocity. This is, perhaps, owing to the great velocity of the stream, the maximum being nearly 16 feet a second, with 4 feet depth of water in the channel.

No. 7A.

January 10th, 1885; 3 p.m. to 6.25 p.m. Current meter No. 3.

Level of Water—																								
No. 1 Staff	3·00								3·05					3·05									3·00
No. 2 Staff	3·00								3·05					3·05									3·00
Station .	10	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45	47	49	51	52
Height of centre of vane of meter above bed. Ft. Ins.	Velocities in feet per second.																						
2 10	4″ 4·74	13″ 7·52	22″ 10·25	11·08	11·08	10·85	11·70	11·56	11·83	13·00	13·15	14·00	13·82	13·30	13·15	13·15	13·00	13·66	13·30	12·69	13 11·56	10″ 9·60	4″ 7·31
		10″	19″																		10″	7	
2 4	..	7·22	10·15	11·20	10·85	10·74	11·20	11·31	11·44	12·24	13·00	13·30	13·65	12·39	12·83	12·39	12·83	13·00	12·52	12·52	10·53	8·89	
			16″																				
			9·69																				
		7″	13″																		7″	4″	
1 10	..	7·90	9·43	11·08	10·74	10·63	11·20	11·08	11·31	12·69	12·69	13·15	13·30	12·39	12·11	12·25	13·15	11·83	12·66	11·70	10·75	8·21	
			10″																				
			9·43																				
		4″	7″																		4″		
1 4	..	7·73	8·81	10·63	10·63	10·63	10·85	11·20	11·31	11·56	12·69	12·39	13·30	12·11	11·83	11·83	13·30	12·11	12·11	11·83	10·63		
			4″																				
0 10	..	..	8·60	10·33	10·43	10·24	10·85	10·24	10·33	11·56	11·83	12·10	12·52	11·83	11·08	11·83	11·83	11·98	11·83	11·31			
0 4	..	..	..	8·15	9·51	8·60	10·24	9·51	10·33	10·43	10·43	11·31	11·83	11·20	10·33	10·97	10·85	11·83	10·43	10·85			

Wind—Calm.

The wind blowing across the stream affected the level of the water at the staffs, raising it on the leeward side.

Having taken all the observations in the transverse section, the time-readings for eighty revolutions of the vane were translated into velocities in feet per second by applying the readings to a curve of coefficients of the meter, which had been ascertained by Mr. R. E. Froude, M. Inst. C.E.

The cross-section of the river where the gaugings had been taken was plotted on accurately divided sectional-paper to a scale of 1 inch to 1 foot. On it, in their relative positions, the vertical sections were marked, and on these at the different depths were plotted the velocities observed. The horizontal scale for the velocities was 4 feet to 1 inch. Through these velocity points a curve was drawn, the area of which represented the discharge past that vertical section in one second. The areas of these curves were computed by an Amsler Planimeter.

The formulas used for determining the discharge for the whole section from the vertical velocity curves were Simpson's and the mean areas.

Observations were taken at different heights of the river from the lowest possible to the highest flood, and the discharges were plotted in the form of a curve having gallons per twenty-four hours as abscissas and the height of water in feet on the staffs as ordinates. The level of the water at the centre of the river was continuously recorded by an automatic water-level recorder. Its application to the gauging will be seen from Plate 8, Fig. 1, and the following brief description.

At the centre of the stream, near the line of the gauging-section, was sunk a cylindrical well, 3 feet deep and 6 inches in diameter, covered with a perforated copper lid, which was flush with the bed of the stream. Leading from this well was a $1\frac{1}{2}$-inch pipe, which entered a deep cast-iron cylinder set in the right bank of the river, in which cylinder the water-level fell and rose with that at the centre of the gauging-section. Partially immersed in the water in the cylinder was a hollow copper float, which rose or fell with the water. This was connected by two wires passing from the centre of the top of the float over two pulleys in a vertical line with the centre of the float to two aniline-dye pens,[1] which moved in a vertical line, one in the same and the other in a reduced proportion to the motion of the float. These pens recorded continually on a roll of paper carried perpendicularly past their

[1] Minutes of Proceedings Inst. C.E. vol. lxv. p. 38.

lines of motion on a drum driven by clockwork, the level of the centre of the stream at the gauging section, the one to a full size and the other to a reduced scale.

The paper was taken by the drum from a spindle set parallel to the axis of the drum, and, passing off the drum, was wound on another spindle also parallel to it, prick points set vertically on the drum, dividing the paper into divisions of twelve hours each, and one roll of paper contained the continuous record of the level of the stream for several months.

The natural-scale pen recorded small variations of the water-level when only a small quantity of water was flowing down the river, the pen throwing itself in and out of gear as the level of the water fell or rose below or above the depth represented by the width of the paper-roll. The reduced-scale pen recorded the water-level to one-eighth full size.

The zero of the lines described by the pens was set to represent the zero of the two staff-gauges at the gauging-section. It was found, however, that for varying depths of water the level, denoted by the clock-gauge diagram, did not correspond with that observed at the staff-gauges, so, in order to compare them, a series of levels was taken of the surface of the stream in the line of the gauging-section for different depths of water in the river. The surface was very irregular, waves extending across the channel in an oblique direction to the centre line. There was also considerable oscillation of the water-level at any one point. Taking the mean level at the different points on the line of section, and plotting it, showed a very irregular surface, though the irregularities became much less as the depth of water increased above 3 feet. Plate 8, Fig. 7 shows the irregularities of the surface for different depths of water in the channel. All the readings proved that there was a depression of the central portion of the stream relatively to the level at the banks, which corresponded with the results obtained by the water-level recorder when compared with the staff-gauge readings.

Curves were plotted, showing the relation between the level of the stream at the staffs and at the centre and mean level of the stream. The centre of the stream was the lowest and the level at the staffs the highest, although there was no important difference between them when the depth of water in the channel was at or above 3 feet.

A scale was constructed from the discharge-curve, giving gallons per twenty-four hours for different levels at the centre of the stream. This scale was applied to the automatic gauge

diagram, divided off into days as previously described, and from it the daily discharge of the river was ascertained.

It has been stated that the current-meter was not used for depths of water below 4 inches on the gauging section. When the depth was less than this, as sometimes happened, another method was necessary for gauging it. The method employed was that of passing the stream over a 20-foot or 10-foot rectangular notch.

The channel below the cement reach for a length of 80 feet was converted into a practically still-water pond while the notch gauge was being used. It was 33 feet wide at the bed, the level of which was 1·5 foot below that of the end of the cement reach. At the end of the 80 feet a concrete bank was made across the channel and part way up the sides, in which was set longitudinally a $\frac{3}{4}$-inch iron plate, 6 inches deep, 3 inches of which projected above the concrete bank, being 7 inches above the bed of the river on the up-stream side. On to this iron plate was bolted a 20-foot rectangular notch, a $1\frac{1}{2}$-inch strip of wood intervening between the notch plate and iron plate as shown in Plate 8, Figs. 5 and 6.

The lip of the notch was $\frac{1}{16}$ inch wide, and it was bevelled off on the down-stream side, the depth below the lip to the bed of the stream on the up-stream side being 1 foot, and the width of the channel at the level of the lip 36 feet. The spaces between the vertical sides of the notch and the banks were filled up with temporary watertight shutters. These shutters were made of 1-inch tongued and grooved planking, fastened on to a 3-inch square timber frame, the bottom and sides of the frame being lined with india-rubber $\frac{1}{4}$-inch thick.

The frame was set on the iron plate, the planking at the bottom and sides reaching down the plate on the up-stream side. When in position, cotters driven through holes in the frame abutted against the down-stream side of the plate, thus bringing the planking into very close contact with the iron plate, and compressing the india-rubber lining against it, by which leakage was prevented. The side of the shutter next to the notch was fastened by a clamp to an iron vertical post, to which the notch plate was attached. These shutters could be fixed or removed in a few minutes, so that when there was any appearance of a flood or any rise in the water that was likely to submerge the shutters (the top of which were 3 feet above the bed of the stream) they could be taken off to allow more waterway, and replaced when the water fell again. At 10 feet from the centre of the notch, up-stream, was a small well similar to that at the gauging-section.

This well communicated with a float-chamber at the clock-gauge, where the level of the water at the well, above the lip of the notch, was recorded on a diagram in a similar manner to that already described for registering the level at the meter gauging-section.

The notch was not used for discharging a greater head of water than 6 inches, as above that depth the area of the overfall became too large in proportion to the area of the channel, and introduced velocity of approach. When the head got very low, the length of the notch was reduced to 10 feet. Francis' formula was used for computing the discharge over these notches; for rectangular notches, $Q = 5{\cdot}35c\ (l - 0{\cdot}1\,nh)\ h^{\frac{3}{2}}$, where $c = 0{\cdot}622$, and n = number of end-contractions of the stream. The notch-gauge proportions were within the limits of the proper application of this formula, while experiments of the most exact nature have since shown its correctness in this case to be within 1 per cent. By this formula a scale was constructed, having gallons per day for different heads of water; and this scale was applied to the notch-gauge diagram for determining the daily discharge for the lower quantities.

These observations, though directed chiefly to determine the daily discharge of the river Vyrnwy, are, owing to the permanent nature of the channel and the method of gauging, favourable for testing the distribution of velocity in the section.

The primary object of all stream-gauging experiments is to find a method by which the discharge of a stream, or river, can be determined with the minimum amount of observation. To obtain this end, much attention has been given to the formula involving the hydraulic slope and radius, viz., $u = c\,\delta_{rs}$, from which the mean velocity is derived without any velocity observation. It involves a very accurate determination of the water-level at the beginning and end of a certain length, which, in a stream like the Vyrnwy, where the surface was very uneven, and where the oscillations of the water-level at the banks was more than 0·1 foot, could not be determined with sufficient delicacy to make the results of much practical value.

The relation between the maximum surface-velocity and the mean velocity of the whole section, is, in the Vyrnwy gaugings very well represented by the formula given by Professor von Wagner,[1] where $v = 0{\cdot}705\ c + 0{\cdot}01\ c^2$, v being the mean velocity of the stream and c the maximum surface velocity. Its application

[1] Minutes of Proceedings Inst. C.E. vol. lxxi. p. 92.

to the Vyrnwy gaugings will be seen from the following Table taken from thirty-three experiments.

				Per cent.
In 11	cases	the error	was less than . . .	1
„ 9	„	„	„ . . .	3
„ 9	„	„	„ . . .	10
„ 4	„	„	over	10, but less than 16.

In three of the cases over 10 per cent., and two under 10 per cent., there was a considerable difference of water-level, and a strong wind down-stream when the experiments were taken, which renders them unfavourable to the application of this formula.

In the majority of cases the formula appeared to give too great a value of v.

The position of the maximum surface-velocity was not constant; it was generally found within a few feet of the centre of the stream, on either side. As the measurement of the velocity at the surface of the stream is one that would be easily obtained, either with a current-meter or a float, and if the position of the maximum surface-velocity could be determined, a result would be obtained in a few minutes, from which the mean velocity of the section could be deduced to within a very small percentage. Should the observation be taken with a current-meter, the meter ought to be properly immersed in the water, so that the oscillation of the water-surface shall not cause the vanes of the meter to be in and out of the water during the observation.

The velocity at the centre of the cross section of the stream, bears a fairly constant relation to the mean velocity. The position is easily found from a plotted cross section, and a reading could be quickly taken with a current-meter.

The Vyrnwy experiments being taken in a regular and symmetrical section, are favourable for testing the relation between this central velocity and that of the mean. The central velocity is always more than the mean, the average ratio being 1 to 0·888, and the greatest variations 1 to 0·932 and 1 to 0·825.

The formula $v = 0{\cdot}738\, v_s + 0{\cdot}05\, v_s^2$, where v = mean velocity and v_s = velocity at the centre of cross-section, gives results much too great in the Vyrnwy gaugings.

A central surface-velocity has been applied by some experimenters to find a ratio to the mean velocity of the section. It can hardly be considered a good observation, as the surface-velocity at any one point is perhaps the most variable in the section, and the most susceptible to disturbance by the atmosphere. It was found in the Vyrnwy experiments to vary from the mean velocity between the ratios of 1 to 0·783 and 1 to 0·943; the average ratio being 1 to 0·834.

A comparison between the central mid-depth velocity and the mean velocity showed a fairly constant relation, the average being as 1 to 0·876 with a range between 1 to 0·825 and 1 to 0·924.

The ratios found at all the different positions mentioned above, appear to be entirely independent of the depth or the velocity of the stream.

A result needing more observation is the mean velocity on the central vertical. Lieutenant Colonel Cunningham, R.E., Assoc. Inst. C.E., Author of the "Roorkee Hydraulic Experiments," found this to be the most trustworthy mode to a rapid approximation to the mean velocity. The area of the curve representing the discharge past the central vertical section divided by the depth of the water represents the mean velocity at that vertical section. The ratio between this central mean velocity and the mean velocity of the whole stream was found in the case of the Vyrnwy to vary between 1 to 0·872 and 1 to 0·990, the mean ratio being 1 to 0·927. These ratios are based upon thirty experiments, in twenty-three of which the difference from the average coefficient is less than 3½ per cent., the depth or velocity of the stream not affecting the relation.

Mid-depth velocities have been recommended by the Mississippi experimenters, as a fairly accurate mode for gauging rivers. This involves a good deal of observation; the mid-depth velocity is slightly greater than the mean velocity of the same vertical section, from which it differs by a small fraction. Taking the mid-depth and the mean vertical velocities in a complete cross section of the stream, the ratio in the Vyrnwy from twenty-one sets of observations at different depths appeared to be about 1 to 0·951, and to range between 1 to 0·929 and 1 to 0·974.

Having taken the mid-depth velocities the mean vertical velocities deduced from them could be utilized for obtaining the discharge, by taking the sum of the products of the mean velocities into the corresponding division areas.

The formula given by the Mississippi experimenters expressing the relation between the mid-depth velocity and the mean vertical velocity, is:—

$$\begin{aligned} V\tfrac{1}{2}D &= \text{mid-depth velocity;} \\ V\,m &= \text{mean vertical ,,} \end{aligned}$$

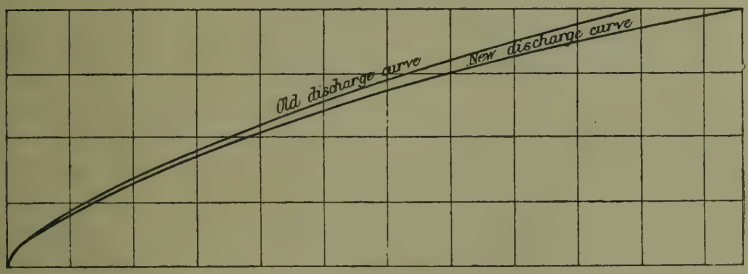
$$\text{where } b = \frac{1\cdot69}{(D+1\cdot5)\frac{1}{2}};$$

$$V\tfrac{1}{2}D = V\,m + \frac{(b\,v)^{\frac{1}{2}}}{12} \qquad v = \text{mean velocity of whole section.}$$

It gives in the Vyrnwy experiments, values of Vm too great by about 2 per cent. on the average, though some experiments agreed within 1 per cent. The lowest readings taken by the meter in the Vyrnwy were between 3 and 4 inches above the bed, and do not throw much light on the bed velocity; but the great increase of velocity between the lowest reading, and that 3 or 6 inches above it points to a very rapid decrease of velocity approaching the bed. Taking the bottom reading in all experiments with more than 1·5-foot depth of water in the channel it was found to vary as the mean vertical velocity, to which it bore a ratio of 0·882 to 1, the greatest differences being 0·841 to 1 and 0·901 to 1.

Professor Unwin has remarked that the mean velocity of the whole section might be found by observations at two positions in the stream, namely one-third the width of the stream, on each side of the centre.[1]

FIG. 2.



The mean of the mean vertical velocities at these positions gives approximately the mean velocity of the section. From twenty-seven sets of the Vyrnwy observations it was found in

			Per cent.
8	sets to be within	. . . . .	1
16	„ „	. . . . .	5
3	„ over	. . . . .	5;

so that its application to fairly regular streams may be taken as a good and rapid approximation to the mean velocity. The velocities at the different points in the cross section, and the figure of the vertical velocity curve will be seen in Plate 8, Figs. 8, 9, 10, 11, which are typical cross sections.

An alteration to the course of the new channel at the masonry dam rendered it necessary to construct a new discharge curve for

[1] Minutes of Proceedings Inst. C.E. vol. lxxi. p. 42.

the gauging section, as the influence of the alteration was considerable.

For purposes in connection with the building of the masonry dam, the river was diverted round the cofferdam AA, Fig. 1, p. 354.

The diverted portion was much narrower than the originally diverted course. Owing to this and to the bend, the water was backed up in the reach above, but shot round the new diversion with great velocity, and the momentum acquired there was not lost before the gauging section was reached; so that the mean velocity for the same depth was increased. The new discharge curve, Fig. 2, p. 365, was much flatter than the old one.

The Author was engaged in the gauging-operations thus described, and he wishes here to acknowledge the kindness of Mr. G. F. Deacon, M. Inst. C.E., the Engineer of the works, in permitting him to make use of the information necessary for this Paper.

The Paper is illustrated by several diagrams, from which Plate 8, and the Figs. in the text have been prepared.

(*Paper No. 2337.*)

"Mining-Appliances in Westphalia."

By Messrs. Malhet, de Gournay, and Suisse.

(Translated and Abstracted by William Silver Hall, Wh. Sc., Assoc. M. Inst. C.E.)

This Paper contains the account of an extended tour among the collieries of Westphalia in November 1884, with numerous notes and remarks on the machinery, appliances, modes of working, &c.

At the Zollverein colliery, which is considered to be one of the best-equipped in Westphalia, air-tubes of corrugated galvanized iron, $7\frac{1}{2}$ inches diameter, costing 2*s.* 9*d.* per lineal yard, are used for ventilating headings. The winding-ropes are of steel, $1\frac{7}{16}$ inch in diameter, and are attached to the cages by being doubled around the sheave, about 16 inches in diameter, of a sort of snatch-block, to the strap of which the cage is suspended. The end is then clamped on to the upper or standing part of the rope by plates and screws. A balance-rope under the cages is used. At No. 2 pit the cages carry two tubs side by side. They are closed by plate-iron on three sides, and when men are riding, doors are hung on the remaining side, a practice generally adopted in Westphalia. No. 3 pit of this colliery is 17 feet 9 inches in diameter, divided into four compartments—one for ventilation, one for pumps, one for two pairs of cages drawing from different depths, and the fourth at present unoccupied. The cylinders of one engine are 37 inches in diameter, those of the other, $49\frac{1}{2}$ inches; the stroke of both is 5 feet 2 inches. The drums, which are cylindrical—26 feet 3 inches in diameter—are all loose on their shafts, to allow for the adjustment of the ropes, each being bolted to a fixed disk by four $1\frac{1}{2}$-inch bolts. There are sixty-four holes available, the distance from hole to hole corresponding to a length of 16 inches on the rope. A screw between the rope-end and the cage allows for close adjustment. The headgear is of iron, of very light appearance, with pulleys 16 feet 5 inches in diameter. As the

[1] The original article appeared in the Bulletin de la Société de l'Industrie Minérale, St. Etienne, 1887, vol. i. pp. 65, 389.

engine-men stand behind the drums of their respective engines, they cannot see the pit-mouth, but regulate the winding by indicators travelling on a board and a movable finger clamped on the rim of the drum. When this comes opposite a fixed point the cage is at the proper level for running-on. The engines are fitted with a safety appliance, in which a nut, travelling on a screw driven from the drum-shaft, releases a catch and applies the steam-brake at the completion of each run, so as to prevent overwinding. The cages are of steel, double-decked, carrying two tubs end to end on each deck.

At the Carlsglück colliery, near Dortmund, the engines have cylinders 3 feet 4 inches diameter, by 5 feet 2 inches stroke. The drums are coned to an angle of 25°, their least diameter being 18 feet, and their greatest 21 feet 4 inches. The pit is 475 yards deep. The ropes are of steel, $1\frac{7}{16}$ inch diameter, weighing 18 lbs. per fathom, and costing 30*s.* per cwt. They are composed of seven strands of eighteen wires each, each strand, as well as the cable itself, having a hemp core. The diameter of each wire is 0·0748 inch, or $\frac{1}{16}$ inch full, with a breaking-strain of 992 lbs., corresponding to 102 tons per square inch. They will stand fourteen to seventeen flexions through an angle of 180°, when held in a vice with jaws rounded to a radius of $\frac{3}{16}$ inch. About 13 feet of the rope is cut off every month, and the wires tested. It is found that while the tensile strength is slightly increased, the resistance to flexion decreases very rapidly; so that at the end of seventeen months a wire will break with a strain of 1,008 lbs.; but will only endure six or seven flexions. When they are found to break with five flexions the rope is changed. The cage-props at bank consist of hydraulic cylinders, worked from an accumulator and a small pump. By turning a cock water is admitted to the cylinders, and the cage raised to the exact position; by allowing the water to escape the cages are released. In winter vaseline is used to avoid freezing, but as the consumption is only 20 lbs. per month, costing 3*s.* 6*d.*, the expense is inconsiderable. Although the arrangement not only saves time in banking, but also avoids the strains on the ropes and machinery due to repeated reversals of the engine, it is very costly, and requires a good deal of maintenance. The boilers are of the Cornish or single-flued type, with corrugated flues of Krupp's steel placed to one side of the centre to facilitate cleaning out the mud. They are fired by the waste gases from the coke-ovens. This colliery is fitted with very complete coal-washing and sorting machinery, which is fully described and illustrated in the Paper.

The Bonifacius colliery, 3 miles east of Essen, and 2½ miles north of Steele, is very fiery, and special precautions have to be taken. In driving parallel roads, holes for ventilation 1 foot in diameter are pierced through the separating wall by means of a hand boring-machine, consisting of a toothed crown, mounted on a stem, passing through a screwed sleeve for feeding up the tool to its work. The stem is composed of short lengths, which are screwed on to each other as the work progresses; and, as the resistance is considerable, the motive power is given by a worm-wheel and worm driven by two crank-handles. Four men can bore 20 yards in eight hours. In the workshops of this colliery extensive use is made of Delta metal (copper, zinc, and iron, a compound which can be forged or cast, but not welded), especially where acid water has to be encountered, as in the valves, bolts, and piston-rings of the pumping-engines. Its cost is about the same as brass, say 9*d.* per lb.

At the Rhein-Elbe colliery a safety apparatus to prevent overwinding is fitted, in which the striking-gear, instead of operating the throttle-valve of the steam-brake, rolls a weight on to the brake-lever. The tubs are tipped by a tippler, worked by an endless screw and hand-gearing, but the latter is generally thrown out of gear, so as to gain increased speed.

At the Prosper colliery the safety-lamps are on the Wolf principle, burning benzene instead of oil. As there is no fear of the gauze becoming clogged by smoke, it is made of thicker wire and finer mesh than usual, having 1,296 apertures to the square inch, as compared with 900 in the Mueseler lamps. They are locked by a ratchet arrangement of special form, which can only be released by a magnet, and the arrangement appears a very good one. The inventor has also contrived a special apparatus for relighting a lamp without opening it, consisting of a paper ribbon dotted with detonating composition fired by a small hammer, and unwound every time the hammer is cocked; but this apparatus appears very liable to derangement, and unless the benzene vapour is previously blown out of the gauze, a rather dangerous explosion is caused. Hanging-lamps are made of larger size than the hand-lamps, and with two, or even three wicks. A special apparatus is used for testing the lamp before issuing them to the workmen, and another special device is employed for charging them with benzene. Both these arrangements are fully described and illustrated in the Paper. The light is better and steadier than that of an oil-lamp, and cost only half as much, but the lamps themselves are very dear, the ordinary ones costing 9*s.* each, and those used by the surveyors and engineers 14*s.* each. Besides a

brick-making plant capable of turning out six thousand bricks per day, there is at this colliery a steam-bakery, and a canteen or barracks, with accommodation for six hundred single men. The cost for lodging, food, light, and washing, is 7*d.* per day. The No. 2 pit is divided into four compartments, two for winding, one for pumping, and one for ventilation. The cages are four-tier, 33 feet high, carrying one tub on each deck. They are made of steel, and the props catch the upper frame. Running-on is done simultaneously at four levels, served by a balance-drop. A peculiar system of signalling has to be adopted. The pit-head pulleys are carried on an enormous tower of masonry, and there is sufficient head-room above the uppermost stage for taking out the cages when required. The south engine at this pit has helicoidal drums with spiral grooves, the diameter ranging from 12 feet 7 inches to 28 feet. The north engine has a cylindrical drum 32 feet 10 inches diameter, and a balance-rope under the cages. The latter gives the best result, both as regards the life of the ropes and facility and regularity of working. The depth is 470 yards, and the run is made in forty-five seconds, or at a speed of 660 yards per minute. This engine, with cylinders 41 inches diameter, by 6 feet 2 inches stroke, was put down in 1879, at a cost, including fixing, of £2,080. The steam-pipe to the pumping-engine is 25 inches in diameter, with copper expansion-joints, and is carried on rollers. When steam is turned full on, the end of the pipe moves from 3 to 12 inches. Formerly steam used to be turned on gradually, but this practice is now abandoned, as it was found to cause frequent ruptures, owing to the unequal heating of the upper and lower sides of the pipe.

The No. 1 pit of the Hugo colliery is 628 yards deep. The cages are double decked, carrying two tubs on each deck, and weigh 32 cwt. each. The tubs each weigh 6 cwt., with a capacity of 10 cwt., making a total weight of 96 cwt. (besides 46 cwt. of rope hanging in the shaft). The ropes are of steel, tapering from $1\frac{1}{2}$ to $1\frac{5}{16}$ inch in diameter, and weighing on the average 16 lbs. per fathom. They last eighteen months, during which 150,000 tons of coal, without counting other matters, is drawn. The wires have a tensile strength of 80 tons per square inch, and will stand twelve flexions. The margin of safety is one-eighth. The drums are helicoidal, from $11\frac{1}{2}$ to 31 feet diameter, and are loose on the shaft. Shaft and drums together weigh 50 tons. The engine, which has a cylinder $35\frac{1}{2}$ inches in diameter, by 5 feet stroke, cost £4,168, has been at work ten years, and has given every satisfaction.

At the Shamrock pit the cage, which carries eight tubs on four decks, weighs 59 cwt., the tubs 48 cwt., the coal 86 cwt., and the rope hanging in the shaft 63 cwt., or a total of 256 cwt. The ropes, which are of steel wire with a hemp core in each strand, are $1\frac{13}{16}$ inch in diameter, and weigh 32 lbs. per fathom. The tensile strength of the wire is 114 tons per square inch, and although only loaded to one-tenth of their breaking-strain, they only last from eight to nine months.[1] At this pit there is a very complete coal-washing apparatus, driven by an engine of 130 HP., and capable of treating 1,000 tons per day of twelve hours. There are three hundred coke ovens of the English pattern, from which the best coke in the district is produced, at a net cost of 11*s.* per ton. The selling-price is 12*s.* 6*d.* per ton. There are also thirty Belgian ovens, but the quality produced is not so good.

The sinking of the No. 4, or Providence pit at the Herne-Bochum colliery, is not yet completed. The head-gear is built of channel iron, and has a very light appearance. It weighs, however, 50 tons, and cost, including erection, £762. The pulleys are 105 feet high to the centre, 19 feet 8 inches in diameter, and with their plummer-blocks cost £75 each. The ropes are round, of galvanized steel wire. The drum is 26 feet 3 inches in diameter, and cylindrical, but in two halves clamped together, so as to allow of the adjustment of the ropes, which overlap each other on the drum as one is wound off and the other wound on. The engine, which is calculated to draw 650 tons per day of ten hours from a depth of 437 fathoms, cost, with the drums, £6,650. The valve-gear is of the Corliss type.

At the Froliche-Morgensonnen colliery, west of Bochum, the valve-gear of the engine is arranged to work with an early cut-off, unless the hand-lever is forcibly held over by the attendant, as there are no notches at the extremities of the quadrant. The tipplers are circular and side-tipping. They are fixed in a cage working in slides, counterbalanced and controlled by a brake. As the cage descends by the weight of the tub and coal, a chain fixed on one side of the tippler tilts it over, the coal being delivered directly into a wagon below. The counterbalance brings the tippler and empty tub back.

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[1] In the original Paper (p. 391) the tensile strength is given as 180 kilograms per square millimetre, or 114 tons per square inch; but this is apparently a misprint, possibly for 130 kilograms per square millimetre. A rope weighing 32 lbs. per fathom would correspond to a solid bar 1·6 square inch in section; and a load of 10 × 256 cwt., or 128 tons, would give 80 tons per square inch, or 126 kilograms per square millimetre as the breaking strain.—W. S. H.

The Hanover colliery, belonging to Mr. Krupp, lies to the north of the one last named, 3 miles from Bochum. This was the first place where Mr. Koepe, the manager, applied his peculiar system of winding-gear. The fly-wheel of the old engine is transformed into a single-grooved pulley 24 feet 9 inches in diameter, by means of blocks of beech-wood bolted to the rim. The head-gear pulleys, 19 feet 8 inches in diameter, are both in the same vertical plane as the fly-wheel. The cages are attached to each end of a single rope, $1\frac{9}{16}$ inch in diameter, weighing 22 lbs. per fathom, of soft iron wire, with a breaking-strain of 41 tons per square inch. There is a balance-rope under the cage, and the load is made up as follows:—

	Cwt.
Cage	44
Four tubs	24
Coal	40
122 fathoms of rope	25
Total	133

and is therefore only $\frac{1}{9\cdot5}$ of the breaking-strain. This, the second rope since the system was adopted in 1877, has been in use for three and a half years, and as yet shows no sensible signs of deterioration. The cages are four-decked, and the catches at bank bear upon their upper frames. There is only one running-on stage, entailing four changes of position of the cage, but these are made very rapidly, as there are no catches or stops at the pit bottom. The length of the rope has of course to be very accurately adjusted, which is done by screw-couplings at the point of attachment to the cages. When the rope is new this adjustment has to be made several times in each turn, but after a few days' work it requires no further attention. At the No. 2 pit of the Hanover colliery Mr. Koepe proposes to fix the fly-wheel, 19 feet 9 inches in diameter, directly over the pit, the rope being guided by two small pulleys 6 feet 6 inches in diameter, and the cylinders being diagonally fixed on a triangular iron frame on the top of the masonry tower supporting the head-gear. The small size of the guiding-pulleys seems to be an objectionable feature in an otherwise economical arrangement. Mr. Koepe's system has been adopted in Upper Silesia, at Stassfurth, and in England; but on the other hand, for reasons which the Authors were unable to ascertain—possibly from the fear that any failure of the rope would stop both sides of the pit—it has been abandoned at Westhausen and Oberhausen, and is apparently making no progress in its

native district, although, as has been shown, the single rope lasts more than twice as long as the two ropes usually adopted. In 1879 Mr. Trasenster instituted an elaborate inquiry into this system and its merits and demerits respectively.[1] In reply to some of his objections, it may be remarked that during seven years no failure has occurred at the Hanover colliery; that, except for excessive depths, the employment of a parallel rope with balance-rope under the cages (for which, of course, an old rope is good enough) gives results as good as, or better than, taper ropes; and that with cages carrying two or four tubs side by side the rope can be continued through the cage and clamped at any point, thus enabling the position of that part of the rope which is strained at "the lift" to be changed from time to time, as is usually done by periodically cutting the ropes every few months. If the dip into the sump does not exceed the clearance height of the head-gear, there is no difficulty in winding water by means of tanks. The cages are fitted with very powerful safety-catches, the maintenance of which in working condition is very carefully attended to.

There is nothing very remarkable at the Friedlicher Nachbar colliery, except some rather special coke-ovens, which were adopted after the Coppée and the Appolt ovens had failed to give satisfactory results. These are fully described and illustrated in the Paper.

At the Rhein-Preussen colliery the headings are driven by Brandt's hydraulic boring-machine.[2] Progress is at the rate of 112 yards per month, three shifts of five men each being employed. The small coal was formerly sorted by an air-blast, but this has been superseded by a washing apparatus, fully described and illustrated in the Paper, with an upward current of water, the air-blast being only used to get rid of the dust. It is capable of treating 500 tons per day, and is driven by a 35-HP. engine. Not only does this arrangement use less water, as compared with an apparatus of similar capacity recently erected at the Concordia mine, but it is far cheaper, the respective costs being £2,500 and £8,000.

The Paper, which is very exhaustive, and is illustrated by eight large plates and about fifty hand-sketches, concludes by descriptions of the Bochum School of Mines, the Bochum steelworks, the

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[1] Minutes of Proceedings Inst. C.E. vol. lvii. p. 407, where, however, the Koepe system is spoken of as already in use at the No. 2 pit.

[2] Minutes of Proceedings Inst. C.E. vol. lvii. p. 405.

Carlswerk (Felten-Guillaume) wire-rope works at Mulheim on the Rhine, and the Humboldt engine-works (formerly Sieviers and Co.) at Kalk.

Attached to the Bochum steelworks is a large barracks for single men, chiefly foreigners from Silesia, who receive board, lodging and washing for 10*d.* per day. For dinner they have a large bowl of soup, and another of sauerkraut and bacon, and for supper a stew and soup. During meals an organ is played. There are baths and a dairy on the premises, and a café adjoining. The average wages of all classes of workmen during 1882–83 was 3*s.* 2*d.* per day.

The Carlswerk wire-rope works is one of the largest establishments of the kind in Germany, and, together with the Grimsberg works at Dortmund, supplies the whole of the Westphalian collieries. Besides iron and steel wire, plain and galvanized, for ropes, fine steel wire for cards is here made. Round ropes are usually parallel, but taper ropes are also made by gradually introducing finer wires, which are welded on to the ends of the coarser ones. For ordinary work, annealed iron wire, with a breaking-strain of 25½ tons, charcoal wire of 35 tons, and cast-steel wire of 78 tons per square inch are used; but, if specially required, they will supply special steel ropes with a strength of 114, and even 127 tons, but these they do not recommend, preferring to supply those of 78 tons per square inch. Galvanized ropes are not much used as yet, except in upcast pits, or where the water is acid, as in the Hartz district, where their use is found to effect a saving in the proportion of 8 to 5.[1] Where men have to be wound, the Dortmund Chief Court of Mines adopt a formula permitting a load on the rope (of course including the weight of the rope itself) of one-sixth of the ultimate breaking-strain; but where balance-ropes under the cages are used, the proportion is increased to one-twelfth, alarm having been caused by a case of breakage which, for no particularly good reason, was attributed to the extra weight of the balance-rope. The formula adopted appears entirely arbitrary. Messrs. Felten and Guillaume, whose experience is very large, recommend a coefficient of from one-eighth to one-tenth in both cases, according to circumstances. As a rule, the users state the general working-conditions, and leave the proportions of the rope to be determined by the makers.

The following general rules (among others) are recommended both by the authorities and the makers:—

[1] It would have been additionally interesting if some data as to the effect of galvanizing on the strength of wire had been given.—W. S. H.

(2) Diameter of drums and pulleys to be at least one hundred times that of the rope.

(4) The bottoms of grooves to be semicircular, of the same diameter as the rope, so as to avoid all tendency to flattening.

(7) All sudden changes of speed in winding should be avoided.

(8) Some yards should be cut off the rope-ends at least every three months.

(10) Whenever possible, spring couplings should be introduced between the rope and the cage.

According to Messrs. Felten and Guillaume, a rope does not lose much of its strength during work, for although the section of the wires is slightly diminished, the tensile strength increases in nearly the same proportion. Certain wires will, of course, break, but a broken wire takes up its share of the strain, and comes into work again at from, say, 5 to 7 feet from the point of rupture, so that a broken wire is useless for a length of from 10 to 13 feet. Therefore, in the case of a rope composed of one hundred and thirty-three wires, and working with a load of one-sixth of its ultimate strength, the fracture of thirty-three wires in a length of 12 feet would reduce its coefficient to $\frac{1}{4 \cdot 5}$, and the rope ought to be condemned. Similarly, a rope with several wires, broken in the same strand or the same section, should be condemned. If the end of a broken wire works up it ought to be nipped off, or it will cause further damage. When a new rope is first put to work, it generally gains 2 or 3 per cent. in length.

Of the thirty-five winding-engines visited by the Authors, twenty-six had round parallel ropes, one had round taper ropes, seven had flat wire ropes, and one had flat aloes ropes. The life of a round rope averages two and a half years, often working double shifts, and they are much cheaper than aloes ropes.

In connection with their visit to the Humboldt works, the Authors describe the following machines, either in progress or recently completed :—

A horizontal winding-engine, with cylinders 3 feet $5\frac{1}{4}$ inches diameter, by 5 feet 11 inches stroke, with Zimmermann cut-off gear.

A plunger pumping-engine, compound condensing, with Meyer valve-gear, to force 1,100 gallons per minute from a depth of 220 yards. High- and low-pressure cylinders, $19\frac{5}{8}$ and $31\frac{1}{2}$ inches diameter respectively; stroke, 3 feet 7 inches, being in the proportion of 1 to $2\frac{1}{2}$. Cylinders and intermediate reservoir (placed beneath them), all steam-jacketed. Pipes and valve-gear so arranged that either can be used independently. The fly-wheel,

15 feet diameter, weighing 10 tons, is fitted with a hand-barring apparatus for starting; there are four plunger-pumps, $6\frac{1}{4}$ inches diameter, worked from the tail ends of the piston-rods, and the air-pump is worked by a lever from the crosshead of the high-pressure cylinder. The engine works at 60 revolutions per minute, giving a piston-speed of 430 feet per minute. Designs for a still larger pump of the same type, of which dimensions are given, were in course of preparation. Particulars, with dimensions and tables of results, are also given of coal-washing machines, tipplers, air-compressors, compressed-air winches, steam traps, and other manufactures of the same firm.

In connection with the Hugo Colliery, full particulars are furnished of the working expenses, rate of wages, and cost of pit wood.

OBITUARY.

ALEXANDER BASSETT, eldest son of the Reverend Alexander Bassett, was born at Great Cheverell in the County of Wilts, on the 28th of April, 1824. He was educated at Marlborough College, and on leaving school was articled to Mr. Thomas Tilbrook, of Horningsham near Warminster, a surveyor and land agent, at that time largely employed in making parish surveys under the Tithe Commutation Act. He remained in Mr. Tilbrook's office for two years, and was afterwards engaged on parliamentary surveys for several projected railways under Mr. Joseph Locke, M.P., Past-President Inst. C.E. He subsequently spent two years in the office of a firm of land agents and railway valuers.

In the spring of 1846, young Bassett was introduced to Mr. W. M. Peniston, M. Inst. C.E., the Resident Engineer, under Mr. Brunel of the Wilts and Somerset Railway. He entered Mr. Peniston's office, and in a few months was appointed assistant engineer on a division of that railway 8 miles in length, including two tunnels, and he retained that appointment until the works were partially stopped. In 1849 he undertook the management of works in connection with the opening of a new colliery near Pontypridd, in Glamorganshire, including the sinking of the pits, and the erection of the machinery; this work occupied him until the autumn of 1850, when he removed to Cardiff, and commenced business as a civil and mining engineer.

In August 1852 he entered into partnership with the late Mr. E. S. Barber, M. Inst. C.E., who, at that time, had a considerable practice as a civil and mining engineer in the counties of Monmouthshire, Glamorganshire and Breconshire. A year later his partner, Mr. Barber, left England, having been appointed by the Eastern Archipelago Company to report on, and direct the operations on, their mineral property in the Island of Borneo, the entire management of the business devolved upon Mr. Bassett. In 1854 the news reached England of Mr. Barber's death at Borneo, thus leaving Mr. Bassett the sole surviving partner. So well and ably had he conducted the many and intricate duties connected

with the several large mineral and other properties under his charge, that in every case the posts held by his partner were conferred on him. He was also appointed County Surveyor for Glamorganshire. His practice now rapidly increased, and extended into the counties of Somersetshire and Gloucestershire, where he acted for several large owners of property. In 1858 and 1859 he acted as Engineer to the Sirhowy Railway Company, and prepared the parliamentary plans for that line (15 miles in length). During the next ten years he was busily engaged in each session of parliament in various schemes for railways, waterworks, &c., either by the promoters or on behalf of the opposition. He was the Engineer of the Cowbridge Railway and of the Pontypridd Waterworks, also joint engineer for the Swansea Vale Railway. He was also frequently engaged in railway and other arbitration cases.

In the spring of 1864 Mr. Bassett's active mind was directed to the great want of better dock accommodation at Newport (Monmouthshire), and of facilities for the development of the enormous mineral wealth of the district; and, as engineer to Lord Tredegar, a large owner of mineral property, he proposed a scheme for new docks on the west side of the River Usk, nearer the mouth of the river than the old docks, and on his lordship's property. His ideas were very favourably entertained; and, at his recommendation, Mr. James Abernethy, Past-President Inst. C.E., was called on to report on the project, with the result that parliamentary plans were deposited that year; the Act was obtained after considerable opposition, and the Alexandra (Newport) dock and railways were constructed and opened in 1875, Mr. Bassett being the Acting Engineer and Mr. Abernethy, the Engineer-in-Chief. These works have proved very successful, and their opening marked a new era in the commercial prosperity and history of Newport.

Mr. Bassett was elected a Member of this Institution on the 6th of March, 1860. He was a member also of the North of England Institute of Mining Engineers, and of the South Wales Institute of Engineers, of the establishment of which he was an active promoter. He was elected a member of its first council, and later on occupied the presidential chair.

The utilization of small coal, long considered of little or no value, and for which scarcely any sale could be found, was a question that Mr. Bassett considered of material importance and one that deserved much more attention than it received. He spent much time and money in carrying out exhaustive experiments in the manufacture of "Patent Fuel" made from small coal by several processes, and

in its trials in the furnaces of locomotive and stationary engines. He was appointed a borough magistrate for Cardiff in 1868. He took an active interest in several charitable organizations to which he devoted much of his time and means. His kindly disposition and love of children was perhaps at no time more apparent than on the occasions of the annual treat he gave to the children of the Industrial Schools, when they were entertained in the grounds of his residence at Llandaff; on these occasions he entered thoroughly into their amusements and games. In character he was frank and truthful, highly honourable, and just in all his dealings, a man in whom his many clients and friends had—and rightly had—the fullest confidence. To the end of his career he pursued the same honoured course, resolved to do his duty to God and man.

Failing health induced Mr. Bassett to remove to Torquay for the winter of 1878, the subsequent winters of 1880 and 1881 were spent at Mentone. The benefit he received from wintering abroad was not of a permanent nature, and on the advice of his physician he afterwards resided at Bournemouth for three years, where he succumbed from severe attacks of bronchial asthma and weakness of the heart on the 8th of April, 1887, at the age of sixty-three.

JOHN BOWER was born at Downpatrick, co. Down, Ireland, on the 8th of December, 1818. His father, William Bower, a native of Banffshire, had been a pupil of Mr. Fleming, of Glasgow; but coming to Ireland in 1809 had settled in Downpatrick, where he married in 1814, Sarah, daughter of John Graham, an eminent mathematician of that day, who had been appointed by the Bishop of Down Diocesan schoolmaster, and to whom young Bower, also a mathematician, had been attracted by similarity of tastes and studies. John was the third child of this marriage—a remarkably quick, active, and clever boy. After being educated by his grandfather, he served the usual time of pupilage under his father, and soon became wonderfully proficient—a providential thing for him; for, having in 1839 lost his father by sudden death, he had at a very early age to take on himself the sole whole charge of his mother and her large young family—his father, through some unsuccessful mining speculations, having been unable to leave sufficient provision for them. This charge he nobly and willingly undertook and carried out, devoting himself wholly to it, and never marrying that he might the more

efficiently supply his father's place, his devoted affection to his widowed mother and sisters being one of the strongest traits in his fine character.

As he was too young to enter on business for himself, he accepted an appointment as assistant to Mr. John Fraser, the County Surveyor of Down, with whom he remained for a time. He soon, however, by his activity and knowledge of work attracted notice, and was appointed on the staff of Sir John Macneill, M. Inst. C.E., being then the youngest of his assistants. In 1841 he was sent into Donegal, and there made a complete survey, valuation, and rearrangement of the Earl of Leitrim's estates, for a public loan, estimating the cost of all necessary work, and, as engineer, negotiating and expending a loan of about £21,000 on the operations.

He continued for several years in Donegal and neighbouring counties, doing work for the Board of Works, various Poor Law Boards, and other employers until 1848.

He was next engaged in various works, surveying, estimating, reporting, and carrying out plans. It may here be mentioned as an instance of his ability, while yet a young man, in planning, drawing, estimating, and carrying out works for the efficient and profitable management of estates, that on one large property—the Earl of Leitrim's—he succeeded in readjusting eleven hundred farms, covering an area of one hundred and eighteen townlands, and so arranging them anew in all their details that, only three of the tenants showed any signs of dissatisfaction. That fact speaks volumes for the tact, knowledge, skill, caution, and ability of so young a man as he was at this time, and the success will be understood to be all the more remarkable, when it is stated that the whole estate had been let on *Rundale* tenure, which makes property in Ireland peculiarly difficult of rearrangement.

In 1851, after making a survey and valuation of the Bogh Union for the guardians, he passed an examination for a county Surveyorship, and after a visit to London, returned to Dublin and took an office, entering into partnership with Mr. Charles Swirey. Next year he explored, surveyed, made plans and sections of 50 miles of the country, from Enniskillen to Sligo, for the Londonderry and Enniskillen Railway Company, in connection with Mr. A. W. Forde, M. Inst. C.E., the Chief Engineer.

From this time his fame spread rapidly, and he so increased in popularity that there is no room in this brief sketch to mention the number and variety of his engagements, though it must be stated that he cared far more for the scientific completeness of his

work than for his own pecuniary advantage, and hence, with abounding work, made little profit. Either as promoter or opponent, he was eagerly sought after by various clients for advice, for evidence, and for arbitration. Besides the surveys and valuations for various unions, such as Enniskillen, Sligo, Donegal, &c., some of the works on which he was principal engineer were: the Finn Valley, the Letterkenny, the Dublin and Antrim, the Belfast Central Railways, and the Northern Union and other extensions of the latter line, all involving severe Parliamentary contests, and, with them, intense anxiety and great expense. As some relief from this mental tension, he accepted a quieter sphere in 1860, being appointed County Surveyor of Carlow, where he remained for sixteen years, during which time many of the most important local works were completed under his direction, for which he received high commendation from the Grand Jury. Finding, however, that his extended professional engagements interfered with his county duties as he wished to carry them out, he resigned the surveyorship in 1877. He had been admitted a Member of the Institution in 1870, and in 1874 was appointed Treasury Inspector for the Board of Works; for some years after, he was engaged in the water-supply of Downpatrick and Warrenpoint. The Letterkenny Railway was the cause of much trouble, expense, and legal complexity to him. After piloting it through rocks and shoals—getting new Acts of Parliament, and re-establishing it after a collapse—the Directors refused to carry out the required conditions which finally wrecked it, and almost wrecked him. In 1884 he retired from all work to Scotland, hoping the rest might in time restore him. But it was too late; similar attacks followed of even severer character, until he was for months hovering between life and death. Slowly recovering, he settled in Edinburgh, where he died on the 31st of December, 1886. Few could have recognized in the gaunt old man—old before his time—who daily was to be seen reading in the Philosophical Institution, the strong, ardent, energetic, and successful engineer of some years back. The testimony of one who knew him best was that he was widely acquainted with current literature; a man of great poetical gifts, having left several unpublished works; wonderfully beloved by his friends and relatives; of a most generous and noble nature, a sanguine and enthusiastic temperament, and a helper—far beyond prudence sometimes—to any brother in need.

JAMES GORDON BRICKENDEN, the second son of Major Lambart Brickenden, late 71st Highland Light Infantry, was born at Warninglid (now Lydhurst), Slaugham, Sussex, on the 30th of May, 1848. He was at school at Glasgow and Leeds, and lastly at St. Peter's Grammar School, York, where he won distinction in mechanical and water-colour drawing.

On leaving St. Peter's, in 1865, he was apprenticed to the late Mr. Joseph Mitchell, M. Inst. C.E., of Inverness, under whom and Mr. Murdoch Paterson, M. Inst. C.E., his partner, he was engaged upon the construction of the Sutherland Railway (Bonar Bridge to Golspie) as assistant to the Resident Engineer. While upon this work he showed himself remarkably quick and apt in picking up information and acquiring professional knowledge.

He was subsequently engaged under Mr. Paterson upon the Parliamentary and working surveys of the Dingwall and Skye Railway (55 miles in length), and as one of that gentleman's assistants, during the period of the construction of the line, he was frequently upon the works assisting the Resident Engineers. Amid the romantic scenery through which these lines pass, he found plentiful opportunities, in the intervals of professional work, of gratifying his artistic tastes by water-colour sketching.

In 1871 he left Scotland to join the engineering staff of the London and North-Western Railway Company, under the late Mr. William Baker, Member of Council Inst. C.E., Engineer-in-Chief, and he remained in the service of the Company until his death. From 1871 to 1875 he was engaged upon the preliminary plans and sections of intended new works, and upon the construction of coal and general depots in the north of London.

In 1875 he was appointed Resident Engineer upon the Seaton and Wansford Railway, 11½ miles in length, comprising some heavy works, including viaducts over the rivers Welland and Nene. On the completion of the Seaton and Wansford line, in 1880, Mr. Brickenden was appointed by Mr. Francis Stevenson, M. Inst. C.E., Resident Engineer on the widening of the railway at Stockport, a work which included the doubling of the Stockport tunnel; and in 1881 he was appointed Resident Engineer on the Denton and Dukinfield Railway (1½ mile in length). In May 1883 he became Resident Engineer on the new Exchange Station, Manchester, then in course of erection, and the widening of the line between that station and Ordsall Lane, through the town of Salford. On the completion of these works in 1885 he entered the Permanent-Way Department as assistant to Mr. S. B. Worth-

ington, M. Inst. C.E., Engineer of the Northern Division of the London and North Western Railway, and shortly afterwards removed to Lancaster.

On Mr. Worthington's retirement, in 1886, the divisions were re-arranged, and Mr. Brickenden was appointed to the new Northern Division, which comprised the northern half of the old division of the same name. From about this time his health began to decline, and a lengthened stay on the Continent in the early part of 1887, when he suffered from the effects of the disastrous earthquakes in the Riviera, did not have the desired result in restoring him, and though he resumed work on returning from abroad, he never completely regained his strength. In the autumn he went over to Dublin to undergo a course of massage, but died there on the 4th of November, 1887.

Mr. Brickenden combined with his professional gifts a keenly appreciative æsthetic sense, for which his favourite medium of expression was painting in water-colours; he was also a good amateur photographer. He took some interest in the study of geology, and was elected a Fellow of the Geological Society in 1878. Of his personal qualities this is not the place to speak, further than to say that his painstaking thoroughness and courtesy inspired respect in all with whom he came in contact professionally, and affection in more intimate circles.

He was a Student of the Institution from October 1872 until February 1875, and was elected a Member in May 1882.

FREDERICK CHARLES BULLMORE, son of a medical practitioner of Falmouth, was born on the 4th of August, 1842, and received his education at the Falmouth Classical School. In 1861 he was articled for four years to the late Mr. C. G. Blatchley, M. Inst. C.E., then Resident Engineer of the Cornwall Railway, and was engaged upon the construction of that line between Truro and Falmouth. In December 1865 Mr. Bullmore, having received an appointment as Assistant Engineer on the Madras Railway, proceeded to India. He was successively engaged in superintending the construction of three districts of the North-West line, aggregating a length of 40 miles, and was in 1867 promoted from the fourth to the third class. In August 1870 his services were dispensed with owing to the completion of the work upon which he was engaged, and in the following month he joined the Engineering Staff of the Carnatic Railway, and was engaged upon the

preliminary surveys of that line at various points between Madras and Porto Novo. On the amalgamation of the Carnatic and Great Southern of India Companies into the South Indian Railway Company in 1874, Mr. Bullmore's services were retained on the Staff of the latter, and he was engaged on the construction of District 2, a length of 16 miles, which he completed without the intervention of a contractor. In August 1876 he left the South Indian Railway, consequent upon the completion of his work, and the Directors of that Company testified their satisfaction with the manner in which he had performed his duties by making him a special grant. In June 1877 Mr. Bullmore re-entered the service of the Madras Railway Company, and was employed until his decease in the maintenance of various divisions of that line.

He died at Bangalore on the 18th of September, 1887, of enteric fever. The Officiating Chief Engineer of the Madras Railway commenting upon the serious loss to the Company's staff of so valuable an officer, states that Mr. Bullmore rendered excellent service in whatever post he occupied.

Mr. Bullmore was elected an Associate of the Institution on the 1st of December, 1868, and was transferred to the class of Members on the 6th of March, 1877.

SAMUEL FITZHUGH COX was born on the 15th of September, 1847, in Barbadoes, where his father, Mr. James F. Cox, of Yatton, in Somersetshire, was then residing for the benefit of his health. Soon after the return of his parents to England, he lost his father, and his education was carried out in the neighbourhood of Bristol. After a year in Germany, he was articled at the age of sixteen to Messrs. Stothert and Pitt, of the Newark Ironworks, Bath, with whom he remained four years.

In November, 1867, at the age of twenty, Mr. Cox passed his examination for the Indian public works as a "Stanley" engineer. He chose the Punjab, and on reaching Calcutta, in March, 1868, was appointed to Amritsar, as Assistant Engineer, 3rd grade, under Mr. W. B. Harington. To Amritsar, Mr. Cox was reappointed at different intervals. The public works upon which he was employed were the New Central Jail, New Court House, Imperial Barracks and Magazine, tramway to fill up the city ditch round the old wall of Amritsar, the formation of a tank, the maintenance of the city roads, and the first 24 miles of the road to Batala. In

1869, Mr. Cox was transferred to Rawal Pindi, where he had to superintend brickfields for the making of large quantities of bricks for the building of a new fort. There were also barracks in course of construction.

In May, 1872, returning to Amritsar, and becoming Assistant Engineer, 1st grade, Mr. Cox had many miles of road under his care: the Grand Trunk road from the Beas to Lahore, 61 miles, and the Pathankote road, besides the station, the jail, and bridges. Here he remained until January, 1875, when he was moved to Sealkote, to superintend the metalling of the Wazirabad road, and was for a short time in charge at Gurdaspur. In November, 1876, Mr. Cox was in camp on the racecourse at Delhi, in charge of preparations for the reception of the native princes during the Proclamation of Her Majesty as Empress of India, which took place on the 1st of January, 1877.

In 1877, he acted as Executive Engineer *pro tem.* of the Gurdaspur division, which extended from Amritsar to Kulu. At the end of this year, Mr. Cox was appointed to Simla, receiving his promotion as Executive Engineer, 4th grade, in April, 1878. Whilst in charge of the Simla Provincial Division he designed and put in hand a boys' school, and several other buildings in connection with the Lawrence Military Asylum at Sanawar. He had also under his charge the important hill road from Simla to Kalka, and its continuation to Umballa; a long section of the Grand Trunk road from Peepli *viâ* Umballa to Loodiana, the hill road from Simla into the interior towards Thibet, and several other less important roads. In addition to these works, Mr. Cox held charge of all civil buildings in the important plain stations of Umballa and Loodiana, and of the hill sanitariums of Subathu, Kasanli and Dagshai, whilst at Simla itself, the residences of the Viceroy and his staff, and of the Lieutenant-Governor of the Punjab, together with the Church, Jail, Treasury, Schools, &c., were in themselves a heavy addition to the work imposed upon him.

At the end of 1880, this large division was broken up, and Mr. Cox went to Amballa until March, 1881, when he took a year's furlough home.

While in England Mr. Cox wrote "Notes on Brick and Tile Manufacture," and "Notes on the present use of Portland Cement and Concrete," published in the professional papers on Indian Engineering, to which he later contributed some interesting notes on the use of old rails in construction.[1]

[1] Roorkee Papers, 1881, pp. 209, 227.

Mr. Cox was again appointed to Amritsar provincial division on his return to India, when he completed a system of rainfall-drainage, designed to prevent the periodical recurrence of the season of sickness and fever. He also prepared plans and drawings for sewage works for the city of Amritsar; but this work was stopped on account of preparations for war, which then appeared imminent on the frontier, in readiness for which large supplies were being collected. The road from Amritsar to Dalhousie, together with that picturesque little hill-resort, were likewise in his care.

Amritsar is an important station of the Church Missionary Society, and Mr. Cox being on their consulting staff, was asked to get out plans for the orphan school; he took much interest in the building of the Batala mission church, and presented designs for a mission hospital and a mission house at Taran-Taran. Mr. Cox was appointed to Jallunder in September, 1886, with survey-work and road-inspection; but in January, 1887, he received orders to proceed immediately to the Bannu Bridge division to construct a bridge over the Kurram, of fourteen spans, of 100 feet each, on the frontier road. Bannu, also, now called Edwardesabad, in honour of Sir Herbert Edwardes, whose brilliant services on the Punjab frontier are associated with that port, is close to the River Kurram. The Waziris, a wild set of men living over the border, and owing no allegiance either to the British Government or to Kabul, are employed on the frontier road. They come down to work in the cold weather, and return to their hills in April to escape the great heat below, and to tend their flocks. In their absence, the work has to be continued by the less hardy inhabitants of the plains. Having got in the foundations of the seventh pier, Mr. Cox took a few days' leave for rest, and joined his wife, at the rather dreary hill-station of Sheikh Budin. Arriving in the early morning after a night's journey up from Bannu, he became ill with cholera at night, and died the next day, August 8th, 1887. At the time of his death Mr. Cox was Executive Engineer, 1st grade. The following telegram shows the estimation in which Mr. Cox was held by his official superiors:—"The Lieutenant-Governor has heard with great regret of the sudden death of Mr. Cox, whereby the services of a zealous and capable officer have been lost to the province, and he desires that, as soon as circumstances permit, you will convey to Mrs. Cox an expression of his sympathy with her sad and irreparable loss."

Mr. Fitzhugh Cox was elected an Associate Member on the

7th of December, 1880, and was transferred to Member on the 6th of November, 1883.

A man of robust constitution, a keen and energetic engineer, ever striving to add to his technical knowledge, and one of the most accomplished architects in the Indian Public Works Department, Mr. Cox has left a gap in the Punjab which will be hard to fill.

SAMUEL BAILEY COXON was born at Seaham Harbour in 1834, a few years after which his father was appointed bank manager at Castle Eden Colliery, under the well-known Mr. John Taylor, of Earsdon. The subject of this memoir may be said to have commenced his career at this colliery as a trapper-boy. Mr. Coxon, senior, subsequently filled the position of agent at Usworth, where he put his son into the joiners' shops, and afterwards sent him on to the heap to assist the banksmen. Being eager for self-advancement, he sought the assistance of Mr. Aitchison, the schoolmaster at the colliery, with whose willing co-operation he managed to acquire a tolerable education. When about sixteen years of age he was put into the office, and then it was that he came under the notice of Mr. Elliot (now Sir George), the managing-owner, who, recognizing something of the qualities which afterwards placed him in such good stead, sent him down the pit to serve his time as a viewer. A very short probation sufficed to show the stuff he was made of, and in 1853 he became manager of Oxclose Colliery; and very shortly afterwards all the collieries owned by Messrs. Johnassohn and Elliot, which comprised those of Usworth, Nettlesworth, Felling, Tyne Main, Penshaw, North Biddick, and Lintz, were placed under his entire control. He was associated in various other enterprises with Sir George Elliot in the North, extending over thirty years. As an engineer he specially distinguished himself in the application of steam-power to underground haulage, and mechanical appliances for mine-ventilation, and in 1871 started what was for some time the largest ventilating-machine in the Kingdom. Amongst the interesting events of his professional career were his visits to Mexico, Canada, and America, in all of which countries he was interested in mining-operations, notably Canada, where he was Consulting Engineer for the coal mines in Nova Scotia, owned by Sir George Elliot and other gentlemen. He had frequently crossed the Atlantic, and on one occasion explored a large tract of

country between Lake Superior and San Francisco in his examinations of the various copper and silver mines in that region. He was engaged in mining operations in Australia, Spain, and Germany, the latter two countries he had visited professionally only recently.

Mr. Coxon's scientific knowledge and attainments received recognition in his being appointed one of the Board of Examiners for Mining Certificates for Northumberland. He was a Fellow of the Geological Society, and of the Geographical Society, and was made a Freeman of London in 1875.

Mr. Coxon's energies were conspicuously displayed in the political contests of the times. He took a very prominent part in the North Durham election of 1868, when Sir George Elliot was returned in the Conservative interest (heading the poll), and for many years represented that division of the county; in fact, Mr. Coxon had so identified himself with the party, that a short time before he left the North of England he was asked by the Conservatives of Gateshead-on Tyne to come forward as a candidate for parliamentary honours. His presence was familiar on many a platform, where as chairman or spokesman he exhibited the calm dignity and eloquence that impress and control the various elements of political meetings. From 1863 until 1882 Mr. Coxon held the office as churchwarden, and at the latter date, on his leaving Usworth, a resolution and vote of thanks were passed at a vestry meeting, and an address was presented fully showing the appreciation of the parishioners of Mr. Coxon's long and faithful services. It may be mentioned that such was his popularity, and the esteem in which he was held by his friends, that he was twice presented with an illuminated address, besides other testimonials of his worth as a neighbour and as a man. Mr. Coxon died on the 26th of December, 1887, at his residence in West Kensington, and was buried at Usworth on the last day of the year. His persevering life and genial character have left incentives to progress and honesty in all classes of his profession, and many tender memories among a wide circle of friends.

He was elected a Member of the Institution on the 30th May, 1876.

JUSTUS DIRKS was born at Bergen op Zoom on the 12th of January, 1825, and received his technical education at the Royal Military Academy of Breda, till he was appointed an Adsperant Ingenieur of the Netherlands, Waterstaat, on the 1st of October, 1845. He served in the Province of Zeeland till 1858, and afterwards on the construction and deviation works of the New-Merwede river at Gorinchem, as an engineer of the second, and then of the first class. In December 1864 he obtained leave to accept the appointment of Chief Engineer of the Amsterdam ship canal, without resigning the Government service, in which he was promoted to the rank of Engineer-in-Chief in 1868. On the completion of the canal, in 1883, he obtained the Order of the Lion of the Netherlands. He also, in 1876, visited Spain, to give an opinion on the land reclaiming works on the lake of Lebrija, and on the Guadalquivir river. In 1879 Count Ferdinand de Lesseps invited him to be present at the International Congress at Paris, to investigate the different schemes submitted for the construction of the Panama Canal, and he visited the spot in company with Count de Lesseps, in the beginning of the following year. Soon after this he went over the Suez Canal, to advise on the proposed widening. He was also consulted by His Majesty the King of the Belgians on the proposed seaport at Heijat, and, in 1882, visited Denmark, to advise on the embankment of Ring Kiöbing. The next year he designed, in Chili, the plans for the construction of the graving-dock at Talcahuani. Several technical writings on river and canal works appeared from his hand during his laborious life, and he was regretted, not only as an engineer of high ability, but as a kind-hearted father and faithful friend, when he died at Scheveningen, near the Hague, after a protracted illness, on the 26th of December, 1886.

He was elected a Member of the Institution on the 3rd of March, 1885.

JOHN GRANT, whose death occurred suddenly on Saturday the 24th of March, 1888, was the eldest son of Ewan Grant of Glasgow, and was born in that city on the 22nd of May, 1819. He had acted as assistant engineer to the Metropolitan Board of Works and the preceding Commissioners of Sewers, for close upon forty years.

Mr. Grant's professional career commenced in the office of Mr. Clinnie, of Paisley, N.B. In 1838 he removed to Devonshire, and assisted the late Mr. Robert Park, of Glasgow, in making surveys for the Tithe Commutation Commission. On the conclusion of this

work, he was employed on the Exeter and Yeovil Railway. In 1845 Mr. Grant married Miss Whitaker, of Exeter, and it is related that, the engineering staff of the above railway being completely worn out by their labours in making the parliamentary survey, this lady, during most inclement weather, and before the completion of the western railway system went alone to London, and arranged for the deposit of the plans. For this service Mrs. Grant was officially thanked by the Directors.

Some articles contributed to the Exeter papers, on the waste of land in the county, brought Mr. Grant under the notice of Lord Ebrington (now Earl Fortescue), and of Mr. Edwin Chadwick, C.B., —the veteran sanitarian—who were both members of the Metropolitan Commission of Sewers, and through their influence he was appointed, in April, 1849, Assistant Surveyor of the commission, his designation being, in 1852, altered to that of Engineer. The district assigned to him was the central, on the south side of the river.

Upon the formation of the Metropolitan Board of Works in 1856, Mr. Grant was appointed Assistant Engineer, and put in charge of the whole of the southern district of the metropolis, the northern district being apportioned, the western half to Mr. T. Lovick, and the eastern portion to Mr. Edmund Cooper; but upon Mr. Cooper's retirement in 1870, these districts were apportioned between Mr. Lovick and Mr. Grant. Mr. Grant taking, in addition to his previous district on the south, the western portion of the northern district, extending as far east as the Ranelagh sewer, and including the districts of Fulham and Hammersmith, Kensington, Paddington, and Chelsea, and a part of St. Margaret, Westminster.

In addition to the general supervision of this extensive district, Mr. Grant superintended the execution of so much of the main-drainage works and street improvements, as were situate within his district; amongst the most prominent of these were, the low-level sewer, extending from Putney to Deptford, with a branch from Spa Road to Deptford, the pumping-station at Deptford, which was the first erected of the four sewage-pumping establishments, the high-level sewer from Balham to Deptford, and its branch from the Crystal Palace to Deptford; the storm-overflow into Deptford creek, which was recently extended by him to the Thames, the outfall sewer, 11 feet 5 inches in diameter, from Deptford to Crossness, and which was carried in tunnel in a curved route under the town of Woolwich; the extensive outfall works at Crossness, embracing a large pumping-station and a covered reservoir of 6 acres.

On the north side of the river, Mr. Grant superintended the construction of a portion of the low-level sewer, and the whole of the Chelsea Embankment, the Albert Embankment on the Surrey side having been previously carried out under his supervision.

Besides the main intercepting sewers, many large works were carried out by him, in connection with the improvement of the main valley lines of sewers, as the Effra and Falcon Brook and deep lines of sewer laid down to convey the drainage of the low-lying parts of Southwark into the intercepting system, and more recently the construction of a tunnel sewer to form an outlet for the drainage of Eltham.

Amongst the more important street improvements, were Southwark Street, the widenings between Camberwell Green and Peckham, and quite recently, the new street in continuation of Great Dover Street, and the widening of Walworth Road.

In November, 1869, Mr. Grant was appointed to act temporarily as Engineer-in-Chief to the Board during the illness of Sir J. W. Bazalgette, and was subsequently thanked by the Board for the able manner in which he had performed his duties.

In the execution of the extensive system of arterial drainage committed to his charge, Mr. Grant naturally had to test the quality of very large quantities of building materials, especially of Portland cement, which had been chosen as the cementing material in the construction of the sewers, &c. In 1858, when Mr. Grant commenced his experiments, Portland cement was looked upon with much suspicion, owing to its then unreliable character. It is chiefly owing to the laborious series of many thousand tests, carried out by Mr. Grant during a period of thirty years, that this constructive material has reached and maintained the high position which it now occupies. Not only were the properties of the cement itself thoroughly investigated, but new uses were found for it. Among these may be mentioned the backing of the granite blocks composing the face of the Albert and Chelsea embankments with cement concrete, instead of with the brickwork or rubble which had hitherto been used for that purpose; and the construction of large sewers of concrete with merely an internal skin or facing of brick. These and other improvements effected a very considerable saving in the construction of the public works entrusted to his charge, and they have since been adopted in numerous similar cases.

The results of many of Mr. Grant's experiments on Portland cement were embodied in three Papers read before the Institution

of Civil Engineers in December, 1865,[1] April, 1871,[2] and May, 1880.[3] For these Papers, a Telford Medal and prizes were awarded to him. Since 1880, Mr. Grant had accumulated the results of a large additional number of tests which it is probable, had his life been spared, would have been communicated to the Institution. He was in constant communication with most European authorities upon cement-testing, and his great personal experience was always at the disposal of those interested in the subject without fee or reward. His investigations were published by Messrs. Spon in 1875.

In addition to the above, Mr. Grant collected the data for, and wrote three valuable reports for, the Metropolitan Board of Works. The first was on the Artizans' Dwellings of Glasgow, and was written in 1877, after carefully examining into the subject on the spot. This report caused him to be invited to give evidence before the Commission on Artizans' Dwellings, of which Lord Cross was Chairman. The second, written in 1881, was on the "Fish-Supply of the Metropolis," and was of a very exhaustive character. In order to collect material for this report, Mr. Grant visited the principal fishing ports of the east coasts of England and Scotland. The third, written in 1885, was on sludge filter-presses, for information on some foreign forms of which a visit was paid to Germany.

Mr. Grant had been confined to his house for a month before his death, having been suffering from pleurisy and cruralgia; but he had notwithstanding insisted upon carrying on his official business, writing a large number of letters daily, and frequently seeing his assistants. Up to 9 P.M. on the day of his death, he was engaged with one of his assistants, and he died of syncope within half an hour afterwards. Of no one could it more truly be said that he died in harness. A letter written to an official at Spring Gardens, was dated 8·30 P.M., an hour before his death.

Mr. Grant was exceedingly painstaking, and aimed at a high standard of perfection in all his work. He was a kindhearted and most conscientious man, who lived out his Christian principles in everyday life, and was affable to all however humble their position. In him the public have lost a good and faithful servant, and his subordinates a kind and considerate superior. He had been a widower for many years, and leaves a son and daughter to mourn his loss.

Mr. Grant was elected a Member of the Institution on the 3rd of December, 1861.

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[1] Minutes of Proceedings Inst. C.E. vol. xxv. p. 66.
[2] *Ibid.* vol. xxxii. p. 266. [3] *Ibid.* vol. lxii. p. 98.

JOHN WILLIAMS was born in Glamorganshire in 1818, and articled about 1834 to Mr. Thomas Morris, engineer and surveyor, Newport, Monmouthshire, an experienced and energetic man, who gave him plenty of work early and late.

On leaving Newport, in 1837, Mr. Williams obtained an engagement on the engineering staff of Mr. Brunel, in the construction of the first line of the Taff Vale Railway from Merthyr Tydfil to Cardiff Docks, and he continued his connection with the Taff Vale Railway Company as Assistant Engineer, acting under Mr. George Fisher, M. Inst. C.E., and afterwards as engineer of new works, up to the time of his death half a century later, when the length of the lines of the Taff Vale railway system amounted to about 100 miles, exclusive of lines in course of construction, and the dividends paid by the Company had been from 10 to 15 per cent. Mr. Williams had great experience in laying out lines of railway as well as in construction, as also an extensive acquaintance with Parliamentary Committees, mostly in cases connected with the Taff Vale Company's interests. He had a considerable private practice, in the course of which he made surveys for, and laid out, important railway lines in England and Wales. Before his connection with the Taff Vale Company he was engaged on various waterworks and similar undertakings.

He was a peculiarly energetic, hardworking, and genial man of business, and even late in life he was generally at work in his office by 9 A.M., although that involved a road and railway journey of more than an hour and a half's duration from the time he left his beautiful residence at Hendrescythan, near Llantrissant.

Mr. Williams married a sister of the late Evan Williams, J.P., of Duffryn Ffrwd, Glamorganshire, who survives him, but he left no children. He died in London on the 5th of September, 1887, only about a week after having undergone a painful surgical operation.

He was elected a Member of the Institution on the 4th of May, 1875.

THOMAS BROWN was born in 1812. He commenced his career as a pupil for five years to Mr. Simon Goodrich, Engineer and Machinist to the Navy Board, and subsequently served for ten years on various stations as an Engineer Afloat in the Royal Navy. He became Chief Engineer in 1847, and in 1863 was promoted to the rank of Inspector of Machinery. He retired from active service in December 1869. With the exception of the ten years

he was afloat, he was, for the whole period of his connection with the Navy, instructor in steam and the steam-engine at the Royal Naval College at Portsmouth, and he was joint author of "Main and Brown on the Marine Steam-engine," one of the earliest treatises on the subject, and for long a text-book at the Royal Naval Schools.

Mr. Brown was elected an Associate on the 6th of March 1860, and on the creation of the class of Associate Member in December 1878 was transferred to that grade. He died in August 1887.

JAMSETJEE NESSERWANJEE DADY was born on the 4th of June, 1846, and was educated in Bombay. For some time he carried on business as a merchant in Bombay, but he had from his youth a tendency towards mechanics, his leisure time being occupied mainly in the study and practice of engineering, and at the age of twenty-seven years he gave up his business as merchant, to follow the profession of an engineer. He afterwards left for England, where he entered the engineering works of Messrs. Hick, Hargreaves & Co., Soho Ironworks, Bolton, on the 4th of June, 1877, remaining there three years, part of the time in the workshops, and afterwards in the drawing offices. He took some interest in the volunteer movement, and, during part of his stay in England, was connected with one of the volunteer regiments. He was obliged to return home on account of being attacked by consumption. After his return to India he was desirous of commencing professional practice there, but, having never properly recovered from his illness, he died on the 10th of April, 1885, at the age of thirty-eight years.

He was elected an Associate Member on the 7th of December, 1880.

CHARLES CAMPBELL DOWNES was born on the 16th of May, 1837. Having served a regular pupilage with his uncle, Mr. William Downes, he went out to India in 1856, and thence to Australia, engaging himself in survey and other similar work. While in Australia, he acquired a practical knowledge of gold-mining at the diggings. In 1859, he was engaged as an assistant engineer on the Jubbulpur line of the East Indian Railway, and upon the suspension of these works, was, in 1861, transferred to the North-West Provinces section, where he held the post of Chief

Storekeeper of the engineering and locomotive departments till 1864. Towards the end of that year, he became Resident Engineer in charge of the railway, mines, and estate of the Quebrada Land, Railway, and Mining Company, in Venezuela, South America, where he conducted the surveys and construction of the line of railway, and the development of the mines; until, from want of capital, these works were suspended in 1866. In November of that year, having failed in obtaining the agency in Bombay of the Great Indian Peninsula Railway, he took charge of the store department of that line up to the autumn of 1868, when he returned home, and, until the end of 1874, practised in London. In January, 1875, Mr. Downes was selected to proceed to Venezuela, South America, to make a report upon the Bolivar Railway and Aroa mines. Upon his return to England, he was appointed Chief Engineer and Agent in Venezuela of the Bolivar Railway and New Quebrada Mining Companies. This appointment he held up to August, 1878. He may, therefore, be considered as the engineer who surveyed and constructed the first railway in the Republic of Venezuela, with which he had, since 1874, been very much identified. He received from the President of the republic the decoration of the Order of Simon Bolivar, in recognition of services rendered to the country, in the progress and welfare of which he took great interest. From 1878 to the end of 1880, he was engaged on professional work in London; from 1881 to 1882, on gold-mines in Venezuelan Guiana; and from 1883 to the time of his death, he was frequently abroad, in South America and elsewhere, reporting upon railways and mining enterprises. His last trip was in connection with a gold-mining property in San Domingo.

He had considerable experience in gold and copper mining; more especially the former, in which he was engaged at various periods, both at the Australian diggings and on the quartz-veins of Venezuelan Guiana.

Mr. Downes was elected an Associate on the 6th of February, 1866, and on the creation of the Associate Member class, was transferred to that grade. He died at St. Thomas, West Indies, on the 22nd of September, 1887.

ROBERT CADDING HEMBEROW was born on the 28th of June, 1849, at Timperley, in Cheshire. He commenced his professional career as Assistant-Engineer on the Grosswardein-Klausenburgh

section of the East Hungarian Railway for Messrs. Waring Brothers and Eckersley, in the years 1868 to 1870. On his return to England he was engaged as Contractor's Engineer on a railway near Chester. In 1874 he was appointed Manager of the extensive works at Carlisle under Messrs. Ward and Ross. These works were undertaken by the Caledonian and the London and North-Western Railway Companies, and comprised an entire remodelling of the Carlisle station, and new lines of way were laid down for the various companies using the Citadel station. Mr. Hemberow had, as contractor's agent, the entire charge of these important works from 1874 to 1878; on their completion, he took charge as Contractor's Engineer of the Bridge Street Improvement Contract, executed by Messrs. Ward and Ross for the Caledonian Railway Company. He was afterwards engaged in a like capacity in the construction of the Cleator and Workington Railway, of which the Engineers were Messrs. Wadham, Turner, and Strongitharm, and the Contractors Messrs. Ward, Ross, and Siddelow, and upon a contract at Barrow-in-Furness, Mr. Stileman, M. Inst. C.E., being the Engineer.

In 1882 he was engaged by Messrs. Eckersley, Bayliss, and Gripper, to take charge, as their agent, of the works at the Algeciras end of the Jerez and Algeciras Railway, and on the death of Mr. Gripper in 1883 he became manager of all the works on this line of railway. In the latter part of the year 1886 he was occupied in the examination of the proposed Santa Marta Railway in Columbia, South America, for Messrs. James Livesey and Son, and he made for these gentlemen a very full and interesting report of this proposed line of railway.

He undertook quite recently for Mr. Woods, Past-President Inst. C.E., to survey and report upon a line of railway between Pontevedra and Carril in Galicia, in the North of Spain, and here it is believed he contracted the illness (typhoid fever) which terminated fatally in London on the 4th of March, 1888.

Mr. Hemberow, in the discharge of the important duties that devolved upon him, gained the esteem and respect of his employers and of all the various persons with whom he came in contact.

He was elected an Associate Member on the 7th of December, 1875.

EDWARD ARTHUR ROBERT INNES, the eldest son of Lewis Charles Innes, a member of the Indian Civil Service, and one of the Judges of the High Court of Madras, was born at

Salem, in the Presidency of Madras, on the 19th of November, 1852. He was educated at Mr. James Hewitt's, at Rottingdean, in Sussex, and afterwards at King's College, London.

Mr. Innes was articled to Sir John Coode, Vice-President Inst. C.E., for three years (October 1871 to October 1874), during which period he was engaged on sanitary and marine works at Weymouth, in the construction of the Corbière Lighthouse at Jersey, and also on the new Harbour Works at St. Heliers. On completion of his term of pupilage, he was engaged by Sir John Coode as Office Assistant from October 1874 to January 1876, during which time he was partially engaged on tidal and other investigations on the River Nene. He was then appointed Assistant Engineer to Mr. William Shield on the Harbour Works at Port Elizabeth in the Cape Colony, which were being carried out under the direction of Sir John Coode. In this capacity he was employed in making marine and land surveys, and in the general conduct of the works, which were executed without the aid of a contractor. Taking a very lively interest in his profession, he threw his whole heart into his work, and proved himself an able, willing, and reliable assistant in whatever service he was engaged. He eminently excelled as a draughtsman, having comparatively few equals. Being of a genial and courteous temperament, he was a great favourite with all who knew him. In the year 1881, he was appointed Resident Engineer to the Natal Harbour Board, and in September of that year he proceeded to Durban to take up the duties of that position, which he held until the time of his death on the 16th of December, 1887. To these duties he devoted himself with great ability and with unflinching zeal and energy, so much so, that there is reason to fear that the long and painful illness, to which he succumbed, was engendered by a chill following upon prolonged exposure to wet whilst making a series of soundings on the bar and in the harbour.

Mr. Innes was elected an Associate Member on the 5th of March, 1878.

WILLIAM HENRY JONES was born near the town of Llantussaint, Glamorganshire, on the 25th of June, 1853. He was educated at the old Cowbridge Grammar School, and was there distinguished for his athletic powers, which stood him in good stead later on in life when traversing the jungles and wilds of the Malay Peninsula.

On leaving Cowbridge he was articled to Mr. Henry Voss,

M. Inst. C.E., one of the divisional engineers of the Great Western Railway, with whom he remained altogether about eight years.

Mr. Jones, while engaged on the Great Western Railway, assisted at the conversion of the 130 miles controlled by Mr. Voss from the broad to the narrow gauge.

In January, 1881, he took an appointment as assistant engineer under Mr. Francis H. G. Caulfield at the Straits Settlements, where he was for some little time after his arrival employed in surveying land and carrying out public works at Taiping. He was then appointed Resident Engineer in charge of the Taiping Waterworks, and superintended those works from the commencement to the end. After this he had charge of the Kurow Road, took the trial section for the State Railway, and was the Resident Engineer during the first year of its construction. He was then placed in charge of the public works in Lower Perak, including erection of lighthouses at the mouth of the Perak River, and the construction of many miles of road through pathless jungle. He also constructed the outlets for the drainage of the town of Telokanson.

In 1886 he was called to Larut, and was placed in charge of the State Railway as Resident Engineer and Traffic Manager, and had the satisfaction to see the undertaking he had commenced completed and opened for traffic. This was the first railway ever made in the province. When it is considered that the line was constructed almost entirely by natives, who had to be instructed at every turn in the method of doing the work; that the country through which the line ran was mostly swamp and jungle; and that the climate, by reason of its humidity, reeked of malaria, it will be acknowledged that the engineer had to contend with difficulties well calculated to test the mettle of any man. The necessary qualities for carrying out this undertaking were happily possessed by Mr. Jones, but the efforts which had enabled him to surmount obstacles, and to see his work well through, proved too great for his strength. He died on the 12th of February, 1887, only a month or so after the opening of the railway.

He was interred at the burying ground attached to the English church at Taiping.

Mr. Jones was elected an Associate Member of the Institution on the 6th of April 1880, having previously been a Student.

CHRISTIAN HENDRICK MEŸER, born at Woodbridge, in Suffolk, in 1830, was the eldest son of Henry Leonard Meÿer. From his earliest he showed a passion for machinery, and a remarkable aptitude in devising many ingenious mechanical contrivances. Educated at a private school, it was his duty for many years to assist in carrying on his father's costly, though for the most part unremunerative, works on Ornithology (Illustrations of British Birds).

Following his natural bent, in 1859 he entered the office of the late Mr. James Walker, Past-President Inst. C.E., and by that gentleman's advice, in 1860 he became the pupil of the late Mr. James Graham. During his pupilage, and subsequently in connection with that gentleman, he took part in the surveys and preliminary designs of many important public works, amongst which may be mentioned the Barmouth, Furness, Metropolitan District, Swindon, Marlborough and Salisbury Railways, the Bute Docks and Railway, the Amsterdam Ship Canal, the Severn Tunnel Railway, the East and West India Docks Extension, the Hull Docks and Railway, &c., &c.

In 1862–3, he rendered energetic and valuable assistance in the works carried out by Sir John Hawkshaw, Past-President Inst. C.E., to deal with the memorable disaster in the fen country, known as the Middle Level Inundation, full details of which are recorded in the Minutes of Proceedings.[1]

Between the years 1867 and 1876 he was engaged on behalf of the contractors (the late Mr. J. T. Leather, M. Inst. C.E., and Mr. George Smith) in assisting the late Mr. Edward Pease Smith, Assoc. Inst. C.E., in carrying out the Dockyard Extension Works at Portsmouth; and owing to that gentleman's illness, for the latter portion of the time he had entire charge of those important works, of which he subsequently contributed a description to the Institution,[2] on the plant and machinery employed, and other engineering arrangements devised for carrying them out, very many of which were of his own contriving. From the year 1877, up to the time of his decease, Mr. Meÿer was again actively and variously engaged in connection with the Parliamentary and other surveys and the preliminary designs for many of the principal railways and other works that have been carried out, or initiated, during that period. His last important work was a survey of the Barrow Harbour and Walney Channel for Mr. F. C. Stileman,

[1] Vol. xxii. p. 497. [2] Minutes of Proceedings Inst. C.E. vol. lxiv. p. 174.

M. Inst. C.E. In his work Mr. Meÿer was distinguished by scrupulous accuracy, carefulness in detail, and readiness of resource: and his opinions on engineering questions, especially those relating to hydraulic engineering, were frequently sought and much valued by his friends. He was in addition not only well read in works relating to his special calling, but also in general literature, and that relating to many of the leading scientific questions of the day, amongst which may be mentioned geology and investigation by the microscope, in the use of which he was most proficient. Of his personal character it may well be said that his gentleness, his unsparing and willing activity in helping others, whether in a professional or private capacity, his strict integrity, and his perfect sense of honour, were especial marks of distinction.

His premature death, on the 21st of November, 1887, was the result of an attack of typhoid fever, contracted in supervising the drainage of a charitable Institution near his home at Clapham, in which he was much interested, and of which he was an invaluable friend and supporter; and his loss is a subject for deep and affectionate regret, not only to his relatives, but also to his many friends and professional coadjutors.

Mr. Meÿer was elected an Associate Member of the Institution on the 4th of April, 1871, and was constant in his attendance and keen in his interest in its proceedings to the end of his life.

ALBERT LEWIS NEWDIGATE, the son of Mr. Francis and Lady Barbara Newdigate, was born on the 29th of March, 1840. He was educated at Eton and Christchurch, Oxford, where he graduated B.A. in 1861. It was at first intended that he should take Holy Orders; but manifesting a strong bent towards engineering, he was articled to Mr. C. P. B. Shelley, M. Inst. C.E. During his pupilage, he was partly employed in the office and partly on the Shrewsbury and North Wales Railway, then under construction. From the autumn of 1868 (shortly after proceeding to M A.) to the end of 1871, Mr. Newdigate was employed under Mr. H. Lee Smith, M. Inst. C.E., in connection with the bridge and other designs for the Lahore and Peshawur (now the Punjab Northern) Railway, and here, as elsewhere, he succeeded in securing his chief's respect and esteem both personally and professionally.

In 1873 he became the representative of Messrs. Henry Lee and Son, of Westminster, the Contractors for the Granville Dock at Dover, and he remained there, under the same contractors, in connection with the deepening works of the harbour, until March,

1879. During the ensuing five years, Mr. Newdigate was occasionally engaged professionally by the same firm, who held his business qualifications in the highest estimation, and who, throughout their lengthened intercourse, entertained for him feelings of the most affectionate regard. In May, 1884, Mr. Newdigate was appointed their resident agent to carry out the foreshore revetment wall and concrete groyne at Hastings, the engineer being Sir John Coode, M. Inst. C.E. He continued there until November, 1886, when he was appointed Engineer to the Dover Harbour Board, a post he held until his death on the 7th of March, 1888.

Mr. Newdigate was elected an Associate Member on the 2nd of December, 1873.

JOHN SEWELL was born at Henderson Knowle, Teviot Head, Cavers, N.B., in 1804, being the eldest of a large family who lost their parents early in life. He served an apprenticeship to a smith and millwright in his native place, and after plying his trade at various places in Scotland, made his way to London. Here he obtained employment at the Woolwich Arsenal, and at Messrs. Rennie and Co.'s Engineering Works at Southwark, until 1837. Having received the excellent common school education of Scotland, and being endowed with all the native shrewdness and push of his countrymen, he rapidly bettered his position. At the beginning of 1838 he was fortunate enough to get a post in the Locomotive Department of the Great Western Railway, under Mr. (now Sir Daniel) Gooch. He remained at the works, which were then at Paddington, until 1841, when, as he was testing the well-known "Etna" locomotive, he had the misfortune to have part of his left-hand torn off by the connecting-rod. As soon as he had recovered from this accident, he was appointed to an office in the Company's Stores Department, holding the post, first at Swindon and then at Paddington, up to 1855, when he resigned. Soon after this he commenced business as a commission agent in coal, iron, and timber, in which commodities he had large contracts with the leading railway companies. He carried on this undertaking with considerable success until 1872, when heavy losses, consequent to the sudden and unprecedented rise in the value of iron, induced him to contract his engagements, and finally to withdraw altogether from the business. Although now within two years of the allotted span of life, Mr. Sewell was as full of energy as most men ten or fifteen years his junior, and his activity found vent in

examining different parts of the country for railway routes, where the accommodation did not exist. In this way he became the promoter of the Swindon and Marlborough Railway, as well as acting as Engineer and Secretary, until the Company was fairly launched, when the engineering works were carried out by Mr. Bidder, Past-President Inst. C.E. This was the last professional work upon which Mr. Sewell was actively engaged, and from it to his death, on the 30th of July, 1887, his time was mainly occupied in writing on various engineering topics. From his first connection with the Great Western Company he took great interest in the steam-engine, especially in its locomotive form, and was a constant contributor to the technical press. Besides ephemeral articles of this nature, he wrote several works, of which the following is a list:—

"A complete set of rules and regulations for the practical management of a locomotive engine and for the guidance of engine-drivers." 4to. plates. 1848.

"Elementary treatise on steam and locomotion, based on the principle of connecting science with practice, in a popular form." 8vo. Plate and cuts. London, 1852-53. (Weale's series.) An extension of this, edited by D. K. Clark, published in 1885.

"On steam-boiler explosions, and the explosive force of highly-heated water." Tract 8vo. London, 1852.

"Thames Embankment. A few reasons why a low-level self-made 6½-mile Thames thoroughfare should be preferred to a high-level tax-made 1½- or 1¾-mile Thames thoroughfare; addressed to the Thames Embankment Commissioners." Tract 8vo. Plate. London, 1861.

"Railway economy, how to restore confidence in railways, &c." 8vo. London, 1868.

Mr. Sewell also occasionally contributed to "Notes and Queries" (2nd and 3rd series), and gave solutions and details relating to many subjects of interest.

Latterly Mr. Sewell devoted much study and attention to the Biblical narrative of the Creation, and embodied his reflections on the subject in a little work entitled, "Theology and Geology reconcilable; or the Biblical Records of the Birth of the Earth much as it is, and of the Deluge as it was, Virtually Verified," but, at the age of eighty-three, death intervened before the book was published.

Mr. Sewell's career was an illustration of what can be attained by force of character, when allied to indomitable perseverance and moral probity. Entirely by his own efforts, he raised himself from the rank of an artisan, wherein he was born, to a position which was at one time one of considerable wealth and influence;

and in doing this his common sense and genial manners enabled him to procure for himself immunity from most of those petty slights and annoyances which so often wound the pride of the self-made man.

Mr. Sewell was elected an Associate on the 2nd of May, 1854.

PATRICK LAMBERT WEATHERHEAD, the second son of Mr. R. B. Weatherhead, Solicitor, and Coroner for Berwick-upon-Tweed, was born at that place on the 15th of April, 1848. He was educated at the grammar school of his native town, where, at Midsummer 1864, he took the Johnston prize for mathematics. In the same year he went to University College, London, and studied under the celebrated mathematician, Professor De Morgan. In the session of 1864-5 obtained a certificate of merit in the higher junior class of mathematics, and took second prize in the experimental class of natural philosophy. From thence he went to Messrs. John Penn and Son's works at Greenwich, where he obtained a thorough practical knowledge of marine engineering, remaining there till early in the year 1874. While with Messrs. Penn he studied mathematics privately, under the tuition of the late Mr. Hogg, of the Royal Naval School, New Cross.

In May 1874 he went to Germany, and joined, as assistant-engineer, the Markisch Schlesische Maschinenbau und Hutten Actien Gesellschaft, Berlin, where he remained till the year 1884. While there he, along with Mr. C. Jüngermann, M. Inst. M. E., designed and constructed a great number of engines for the most important vessels of the Imperial German Navy; among these may be mentioned the engines for the despatch vessel "Blitz," a full account of which appeared in 'Engineering,' of August 20th, 1884.

On Mr. Jüngermann being appointed a director of the company, Mr. Weatherhead became Chief Engineer, and continued in this position until early in 1884, when failing health compelled him to leave the company's service, and to seek the warmer climate of Mentone. His health having been somewhat restored, he returned to Berlin, where he acted for about twelve months as a consulting engineer, and in the following year he accepted the position of engineer in the Stettiner Maschinenbau Actien Gesellschaft, at Stettin. Here he remained until January 1887, when again, in consequence of failing health, he had to seek the milder climate of the South of Europe, and was in Mentone with his sister when the terrible earthquake of February in that year took place. He was compelled then to go to

Montreux, where he remained till about the month of April, when he received an appointment as engineer in the works of Messrs. Portilla, White and Co., of Seville, in Spain, taking charge of the designing and constructing department. He returned to his native place in August of the same year for a holiday, but his health utterly failed, and he lingered on, getting gradually weaker, until the end came on the 12th of January, 1888.

Mr. Weatherhead was elected an Associate Member on the 3rd of February, 1884. He was also a Member of the Institution of Mechanical Engineers, and a Member of the Society of Naval Architects at Berlin.

ROBERT CHARLES LINDLEY, son of Charles Lindley, was born at Mansfield, on the 7th of January, 1824. His first connection with engineering was in the early days of railways, when he was engaged in the construction of the Ashford and Sandwich line, now forming part of the South Eastern Railway. He was afterwards employed for three years in Denmark, and was responsible for the laying out of most of the first-made railways of that country. On returning to England, he was employed by Messrs. Grissell and Peto, the Contractors, on the foundations of the New Houses of Parliament. During the progress of this work, Mr. Lindley's interest was greatly aroused in the controversy as to the kind of stone proposed to be used in the superstructure. As a result of his inquiries and investigations, he was induced to embark in the purchase of quarries at Mansfield, Notts, and the last thirty years of his life was spent in developing the use of the stone they produce, the Mansfield stone being now known as one of the best in England for engineering and building purposes. Mr. Lindley died on the 5th of June, 1887. He was elected an Associate on the 1st of April, 1845.

THOMAS ROUTLEDGE was born in 1819. He began his working career as a manufacturer of scagliola and terra-cotta at Lambeth, and was so engaged when he was elected into the Institution on the 9th of May, 1841, his proposer being Mr. Joshua Field, Vice-President. He appears to have followed this business until about the year 1856, when he was induced to take up paper-making. In this latter industry he was destined to bring about a revolution that

fairly entitles him to recognition as a national benefactor. He took a paper-mill at Eynsham, near Oxford, and at once began experimenting on substitutes for rags, the supply of which was then barely equal to the demand, and threatened soon to become inadequate. Mr. Routledge, at the instance, probably, of the Marquis of Bassano, turned his attention to the now well-known esparto grass of Spain and Algeria, which possesses in a peculiar degree the long tough fibre sought for by the paper-maker. In 1856, 50 tons of this material were imported into the United Kingdom, and, the initial difficulties incident to a new manufacture having been overcome, Mr. Routledge began the manufacture of esparto paper on a commercial scale. He wrote a pamphlet recommending its use, which was printed on the new material; but no amount of advocacy seemed to avail to induce the trade to take up esparto, and until 1861 Mr. Routledge remained its only user. In this year, the duty being repealed, the demand for paper went up with a bound, and concurrently with this came a gradual decline in the supply of rags, due to the outbreak of the American war, and the resulting cotton-famine. The paper-makers were forced to capitulate, and began gradually to adopt Mr. Routledge's process. The importation of esparto rapidly grew till it reached 50,000 tons in less than ten years from 1856, and in 1886 had increased to 200,000 tons. About 1862, perceiving the advantageous situation of Ford paper works on the Wear, Mr. Routledge was drawn to the district with which his after life was indissolubly bound up. The works were at that time owned by Messrs. Blackwell and Co., of Newcastle. Mr. Routledge became the purchaser, and in 1864 he converted his undertaking into a limited liability company, which he continued to the last to direct with consummate business ability. Having firmly established the manufacture of paper from esparto grass, Mr. Routledge continued for many years to improve and extend the new industry, devoting all his time and energies to its development. Later on he paid considerable attention to investigating the suitability of bamboo as a paper-making material, and published a pamphlet on this subject in 1875. This treatise, like the others in which he had advocated the use of esparto, was printed on paper made from the substance recommended in its pages. He was in constant communication with the Director of the Royal Gardens at Kew in reference to the cultivation of bamboo, and records of that establishment contain many valuable descriptions of his experiments upon samples of this plant submitted to him for the purpose. Many other vegetable fibres were also experimented upon by Mr. Routledge;

indeed, he was recognized in the trade as the highest authority in this department, and it was quite customary for him to receive parcels of fibre from all parts of the world to be tested and reported upon as to their commercial value. It is at present too early to say whether the bamboo is destined to supersede esparto; but, in any case, Mr. Routledge showed the way in the production of cheap paper. To his courage and perseverance the country owes the development of an industry that employs many thousands of hands. Like all reformers, he had difficulties to encounter and discouragements that would have proved insuperable to a less vigorously constituted man; but his technical knowledge, allied to business capacity and great tenacity of purpose, enabled him to overcome them all. For the last three years Mr. Routledge had been in failing health, suffering greatly from bronchial asthma complicated with gout; a recent visit to Wiesbaden having failed to effect any improvement in his condition, he became gradually worse, and died in London on the 17th of September, 1887.

Mr. Routledge was a man of considerable scientific attainments. In addition to his long connection with this Institution, he was a member of many other scientific societies, including the Geological Society, the Linnæan Society, the Royal Botanical Society, the Royal Geographical Society, the Society of Arts, the Institution of Mechanical Engineers, the Society of Chemical Industry, and the Royal Colonial Institute. He was also on the committees of the Papermakers' Association, and the Papermakers' Club. The only body with which he was associated in his own neighbourhood was the Sunderland Chamber of Commerce, on behalf of which he was occasionally delegated to attend the meetings of the Associated Chambers of Commerce.

HENRY WILLIAM SCHNEIDER was descended from an ancient Swiss family of the Canton of Berne, a member of which settled in England towards the middle of the last century. In due time, Henry William Schneider succeeded his father and grandfather in the merchants' business founded by the latter in London. The firm was extensively concerned in Mexican affairs, and for many years acted as financial agent of the Mexican Government, under which it held large contracts for the coinage of silver. It had a considerable establishment at Guanajuata, where for many years it coined an annual average of two millions sterling in gold and silver. In the ordinary course, Mr. Schneider's career

might have been confined to the inconspicuous, though honourable, vocation he had chosen; but the chance of distinction, which is said to occur once in the life of every man, came to him at a moment when he was quick to seize it. In 1839, being on a touring expedition in the Lake District, Mr. Schneider was impressed with the great mineral wealth of the locality. He was introduced to Mr. Jopling, the Agent of the Earl of Burlington (the present Duke of Devonshire) who managed the slate-quarries at Kirkby. This gentleman took Mr. Schneider to see the ancient workings on the Park Mines at the north end of Park Farm. In the result Mr. Schneider determined to try his fortune in exploring for iron ore on Lord Burlington's land. In the early part of 1840 he took a lease of the property, and worked it with very moderate success for two years. With characteristic pertinacity and determination, Mr. Schneider, in the meantime, successively purchased the Whitriggs Mine, and leased the Mouzell estate. The first of these ventures was unsuccessful, but the latter mines were worked very profitably from 1845 to 1878. During the year 1850, Mr. Schneider, having practically ceased to work the Park Mines, was called upon either to surrender his lease or to make some further trials. With this alternative before him, Mr. Schneider determined to sink a pit on a spot selected in 1840, which had then been abandoned on account of his meeting with no support from his mining neighbours. At first, here as elsewhere, want of success pursued him, till at last the time came when he had exhausted his resources. Then, like an honest man, he went to his workmen, and told them they must go home as he could no longer pay their wages. The men, however, declared that they could not bring themselves to leave such an excellent master in the lurch, and that they would work on for another week without pay. The day after this arrangement was made the men struck the famous vein of ore that altered the fortunes of the disheartened prospector, and made Barrow a Lancashire Chicago. Some idea of the magnitude of the deposit at Park may be formed when it is stated that the average raising for thirty-four years has been 250,000 tons per annum.

Mr. Schneider, being still engaged in commercial business in London, and not being able to devote the whole of his attention to the mines, the business of which had so largely increased, determined in the early part of 1853 to take as partner the late Mr. Robert Hannay.[1] The question of smelting ore in Furness

[1] Minutes of Proceedings Inst. C.E. vol. xl. p. 261.

had often been mooted, but the immense difficulty of procuring fuel led to a total abandonment of the idea until railway communication had been established, which was in 1857, when Messrs. Schneider, Hannay & Co. took up the question of erecting furnaces. In 1859, they secured land at Barrow for the purpose of erecting furnaces, this place being selected because of the facilities it afforded for the shipment of hematite pig-iron, which was in large demand in South Wales, Scotland, America, and elsewhere.

At this period coke was brought to Barrow, *viâ* Leeds and Lancaster; but the distance being great, and the route expensive, overtures were made to Messrs. Schneider, Hannay & Co. to join with Messrs. Pease in the construction of a railway to connect the north-west of England with the coal-fields of Durham—from Barnard Castle to Tebay, and accordingly they became large shareholders in this company. This railway was opened about 1862, causing the production at the mines to immediately increase to an immense extent.

In 1847, and at the time when the furnaces at Barrow first commenced smelting, the quantity of ore exported from Barrow by ships amounted to something like 500,000 tons per annum. Mr. Schneider at this time became the owner of a line of steamers for carrying this ore from Barrow to South Wales, and he also used a fleet of flat-bottomed boats for the purpose of taking the ore across Morecambe Bay to Morecambe, from which place it was afterwards sent by rail to the Durham and Newcastle district.

In 1863 it was determined to erect steelworks at Barrow, the principal shareholders of which were the Duke of Devonshire, Mr. Schneider, Mr. Hannay, Mr., now Sir James, Ramsden, and the Duke of Buccleuch.[1] This Company had hardly got to work before it was found that the interests of the Ironworks (belonging exclusively to Messrs. Schneider, Hannay and Co.) clashed with the interests of the Steel Company; and, moreover, that a large increase in the number of furnaces was desirable, and that the Steelworks, to be successful, should be enlarged. This led to an amalgamation of the interests of the two Companies, and on the 1st of January, 1866, Schneider, Hannay and Co., as a firm, ceased to exist, and the Barrow Hematite Steel Company, Limited, was formed, of which the Duke of Devonshire became Chairman, with Mr. Schneider, Mr. Hannay, and Sir James Rams-

[1] Minutes of Proceedings Inst. C.E. vol. lxxvii. p. 347.

den as directors; but Mr. Hannay retired during the first year. Mr. Schneider, however, remained a director, and was the largest shareholder next to the Duke of Devonshire. When the Company was formed, there were six furnaces in operation and two ready to go into blast. In 1887 the number of furnaces was fourteen, and thirteen of these were in blast, producing 350,000 tons of pig-iron per annum; while the steelworks were producing in rails, tin-plate, bars, angles, billets, and merchant steel, including fish-plates and ship-building steel, girders, steel boiler-plates, &c., about 220,000 tons per annum.

Mr. Schneider was a promoter and a director of the Barrow Flax and Jute Works from its commencement, and also of the Barrow Shipbuilding Company; and in connection with both of these institutions he not only devoted great energies, but contributed liberally towards the necessary capital. The subject of this memoir was one of the original aldermen of the borough when the town was incorporated in 1867, and he not only maintained this position up to the time of his death, but occupied the civic chair for the three years extending from November 1882 to 1885.

Mr. Schneider was an *ex officio* representative of Barrow on the Ulverston Board of Guardians, and in 1862, when the Union Assessment Act was passed, he was elected Vice-Chairman of the Assessment Committee for the Ulverston Union, with the Duke of Devonshire as Chairman. He was unanimously elected Chairman of the Barrow Board of Guardians at the original formation of that Board in 1867, and held the post with great credit to himself up to the period of his death. He was also one of the first members of the Barrow School Board.

Mr. Schneider was elected Member of Parliament for Norwich in 1857, and again in 1859. He was, however, unseated on petition in 1860, and the same ill-luck pursued him five years later on the occasion of his being elected for Lancaster. At the election of 1885 he was a candidate for Barrow, but was defeated by Mr. David Duncan, who in turn was unseated in the following year on Mr. Schneider's petition.

Mr. Schneider was for several years connected with the Furness Volunteer Battalion. He was first lieutenant in the Barrow Company, and became captain of the Dalton Company in 1861. In 1862, he took at his own expense the united companies of Dalton and Barrow to London to visit the Exhibition.

His death, on the 11th of November 1887, fell upon the town of Barrow as a public bereavement, and his funeral was the occasion

of a demonstration that betokened the high estimation in which he was held.

Mr. Schneider was elected an Associate of the Institution on the 1st of March 1864.

CHARLES WARING was the third son of Mr. John Waring, a well-known contractor for public works. He was born at Eccles-hall, near Sheffield. On the completion of his school life, he became associated with his father, who constructed many important public works. He afterwards became a partner in the firm of Waring Brothers, railway contractors, who carried out large and important contracts in England, France, Belgium, Spain, Portugal, Austria, Hungary, India, and South America. In recognition of his public services, he was made a Chevalier of the Order of Leopold of Belgium, and of the Order of St. Maurice and St. Lazarus of Italy.

Mr. Charles Waring was Member of Parliament for the Borough of Poole in the Liberal interest, from 1865 to 1868, and had been active in politics ever since, being of late a Liberal Unionist. He was a frequent contributor to the 'Fortnightly Review,' and wrote about Brazilian railways, the Future of Industry, the Suez Canal, and the State Purchase of Railways, &c. The articles on State Purchase of Railways have recently been enlarged upon and published by Messrs. Chapman and Hall in book form. This book has attracted much attention throughout the country. He was a man of remarkable energy and sterling qualities, possessing great force of character and ability.

Mr. Charles Waring was elected an Associate of the Institution on the 1st of April, 1851. He died at Wycombe Abbey, High Wycombe, on the 26th of August, 1887.

WILLIAM WEBSTER[1] was born at Wyberton, a small village near Boston, Lincolnshire, in May 1819, and was apprenticed to Mr. Jackson, builder, of Boston. The day after he was out of his apprenticeship (having never worked as a journeyman), he commenced business on his own account at his native village, and carried out works of a somewhat important character, such as

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[1] A melancholy interest attaches to this notice of Mr. Webster in that it was prepared by his personal friend and neighbour Mr. John Grant, M. Inst. C.E. Before he could correct a proof of it Mr. Grant was himself dead. Ante, p. 389.

building and restoring churches in Lincolnshire, Nottinghamshire, and other counties, the erection of sluices, the construction of the Corn Exchange, the reading-rooms, and the oil-mills at Boston, &c. He restored, amongst others, the beautiful church of Algakirk, near Boston, the Architect being the late Sir Gilbert Scott, and also assisted in the restoration of the well-known parish church of that town. In 1856–7, he built the Cambridge Lunatic Asylum at Fulbourne, and on its completion entered into a contract for the erection of the Three Counties Asylum, near Hitchin. In 1860 he took up his residence in London, and succeeded in obtaining, among other contracts, those for the formation of the Southern Outfall Sewer, the Crossness, Abbey-mills, and Western pumping-stations, together with a considerable portion of the main sewers on the north and south sides of the Thames. He also built a portion of the Victoria Embankment, the whole of the Albert and Chelsea Embankments, the foundations of St. Thomas's Hospital, and the extension of the embankment of the Houses of Parliament. While these were being carried out, he took many other contracts in London and in the country, amongst others, that for the great scheme of the Metropolitan Sewage and Essex reclamation Company, and received heavy pecuniary compensation when the works were stopped, the Holborn Viaduct Railway Station and Hotel, the middle level outfall sluice in Norfolk, the waterworks at Hampton, the gasworks at Poplar, the new bridge at Maidstone, &c. Mr. Webster died at his residence, Wyberton House, Lee, on the 1st of February, 1888, and was interred at St. Margaret's, Lee, in the presence of a large circle of friends, who attended to testify their respect, and to pay a last tribute to his memory.

Mr. Webster was elected an Associate of the Institution on the 1st of December, 1868.

*** The following deaths have occurred, or been made known, since the 20th of February last, in addition to some of those included in the foregoing notices:—

Members.

Crampton, Thomas Russell.
Geneste, Frank Alexander Brown.
Hack, Thomas.
Harrison, Thomas Elliot (*Past-President*).
Kunhya Lall, *Rai Bahadoor*.
Piercy, Benjamin.
Potts, Arthur.
Robertson, Henry.
Rogers, William.
Simpson, David Lees.
Townshend, Richard.
Wright, Benjamin Frederick.

Associate Member.

CROWE, WILLIAM MILNER.

Associates.

SMYTH, WILLIAM SCOTT. | WIGHT, THEOPHILUS GEORGE.

Information respecting the life and works, the career and leading characteristics, of any of the above, is solicited, to aid in the preparation of future Obituary Notices.—SEC. INST. C.E., *May* 3, 1888.

Sect. III.

ABSTRACTS OF PAPERS IN FOREIGN TRANSACTIONS AND PERIODICALS.

The Want of a Uniform System in Experimenting upon Timber.

By F. A. Campbell.

(Transactions and Proceedings of the Royal Society of Victoria, 1887, p. 244.)

The Author suggests the co-operation of persons interested in experiments on the strength of material towards the introduction of some system as a guide for future experimenters on timber. He formulates six minor points which should be carefully recorded in connection with any series of experiments; so that much otherwise valuable work may not be rendered almost useless. They are—

1st. *Age of tree.*—Here it is only of consequence to know that the test-piece has been taken from a tree neither in its earlier nor in its later stages of existence.

2nd. *Locality of growth.*—The geological nature of the soil wherein a tree grows has a great influence upon the character of the timber. It would appear from a comparison of experiments that the closer any particular kind of tree approaches equatorial regions the stronger is the timber produced. The Author does not know if this rule is absolute, but it is not unreasonable to suppose that it may be so, seeing that some of the strongest woods are produced in the tropics; as, for instance, the Krangi, of Borneo, the ironwood of Borneo, the West India Mora, and the Ironbark of Northern Queensland.

3rd. *Part of the tree from which the specimen is cut.*—The heart-wood is the only part fit for practical use; also the butt appears to afford timber of greater density and strength than the top.

4th. *Length of time seasoned.*—The process of seasoning makes some timber stronger, others weaker. The Author quotes Baron von Müller to show that timber from trees of the Eucalyptus family is strengthened by seasoning. On the other hand Mr. Laslett, in his work on "Timber and Timber Trees," shows by experiment, though the resistance to crushing in oak is greater when seasoned than when green, the transverse strength of different kinds of pine trees is greater when green than when dry.

5th. *Deflection as affecting the bending moment of a beam.*—The customary formula for the bending moment of a beam loaded in the middle and supported at each end, $\frac{w\,l}{4}$ expresses the bending-moment only so long as the beam retains its original form and position, for whenever deflection begins two new elements are introduced which affect the result. In the first place the three force

acting on the beam cease to act in parallel lines; and in the second place the beam is lengthened by moving over the points of support as it deflects. In cases, then, of large deflection the formula $\frac{w\,l}{4}$ is misleading, and although sufficiently accurate for ordinary practical use, should, in all cases of experiment, be replaced by the formula $\frac{w\,l}{4}\,\mathrm{Sec}^2\,\theta$, θ being the angle of deflection.

6th. Size of piece tested.—It is the practice to assume that the strength of timber as a tie, beam, or column, varies according to the sectional area exposed to the strain, in which case the size of the specimens tested would not affect the result. A comparison of experiments on large and small scantlings tends to prove, however, that the smaller the dimensions of the piece tested, at all events in the case of beams, the higher proportionally is the moment of resistance. Without attempting to explain the reason, the Author contents himself with recording in a table derived from the publication of various authorities the facts which seem to establish this proportion.

In addition to these six minor conditions which should be recorded in any series of experiments, the particular species of timber to which each piece tested belongs must to be thoroughly established. Local or popular names are almost useless for this purpose; the true botanical nomenclature must be used. Some of the most extensive series of experiments carried out in Britain and in the Australian colonies fail lamentably in this respect, and work which must have taken much time and cost much money is thus seriously diminished in value. In conclusion, the Author, while welcoming the prospect of systematic work with the testing-machine by men of science, urges others not to be deterred by the want of scientific apparatus from experimenting when they have the opportunity. "All that is necessary is the inclination for the work, coupled with care and patience in carrying it out. The roughest bushman in the interior, breaking a few sticks with weights, and telling us all that is to be known about these sticks and about these weights, adds to the knowledge of the world; and his rough work, if only careful, true, and full, may rank with that of high officials who work in dockyards or laboratories with perfect machines and paid assistants."

F. G. D.

On the Abrasion of Cements and various Mortars formed from them. By Dr. Böhme.

(Mittheilungen aus den Königlichen technischen Versuchsanstalten zu Berlin, 1887, p. 108.)

The extensive use of cements in the manufacture of floor-tiles and hearths, led the Author to believe that experiments on the abrasion of such material would have a considerable practical

interest. The test-pieces were submitted to the grinding action of a horizontal revolving disk, against which they were pressed by means of a lever so loaded at the free end that a pressure of 25 kilograms (55·115 lbs.) was applied to the piece, the latter being a cube with a surface of 50 square centimetres (7·75 square inches).

At first a disk of composition metal was employed, but this was afterwards replaced by one of cast-iron; dry emery was used for grinding. The disk had a diameter of 22 centimetres (8·66 inches), and revolved at the rate of 22 revolutions per minute; at this speed, thirty turns were made for each test, and 20 grams (0·704 ounce) of emery were supplied at starting, and the same quantity after fifteen revolutions were completed.

Test-pieces of neat cement, and of cement mixed with various proportions of sand, were tried; in each case two samples, one seven days and the other twenty-eight days old, were tested.

The loss by abrasion was ascertained by carefully weighing the pieces before and after the experiments.

Twenty-eight kinds of cement, supplied by different manufacturers, were investigated as regards:

(1) Their general character;

(2) Their strength in tension after seven and twenty-eight days;

(3) Their abrasion for mixtures of cement and sand in the ratios of from 1 to 0 to 1 to 5 of the former to the latter, and after setting for seven and twenty-eight days respectively.

The following Table, compiled from the original, shows some of the results of the abrasion-tests:—

ABRASION.

	Seven days old.						Twenty-eight days old.					
	Mixture (cement + sand) by weight.											
	1+0	1+1	1+2	1+3	1+4	1+5	1+0	1+1	1+2	1+3	1+4	1+5
No.	Cubic centimetres.											
28	6·1	2·3	3·2	3·9	6·7	7·6	5·8	1·4	2·0	2·8	5·1	12·6
10	8·5	2·8	2·6	5·1	5·8	11·8	5·4	1·4	1·7	2·9	3·7	5·0
5	4·6	2·1	2·6	3·9	9·6	21·4	3·8	1·6	1·5	3·0	3·5	12·0
8	3·9	2 1	2·3	3·6	7·5	20·2	4·2	1·6	1·8	2·5	3·0	11·7
14	6·6	3·2	2·5	6·7	19·7	24·7	3·9	2·6	1·7	4·1	10·4	15·7
26	4·9	2·9	2·7	4·0	8·8	15·7	4·7	1·6	1·6	3·4	3·7	10·4
9	7·4	3·1	4·3	4·2	16·0	18·6	4·7	1·6	1·8	3·3	5·6	9·9
21	3·8	3·1	5·2	7·6	12·7	17·2	5·2	2·7	2·6	5·2	9·3	18·3
19	5·3	3·4	3·8	5·8	10·6	46·9	5·1	2·8	1·8	5·1	6·9	27·4

The original is illustrated by several diagrams in which the results are plotted as curves.

G. R. B.

On the Influence of Low Temperature on Cement Mortars.

(Jurnal Ministerstva Putei Soobstchenia, St. Petersburg, Jan. 1888, p. 13.)

It is well known that water containing common salt in solution freezes at a lower temperature than fresh water, and it has been proposed to take advantage of this property in preparing mortars for use when the temperature is below the freezing point. Experiments were instituted in which hydraulic lime and Portland cement were mixed with fresh water and also with water containing in solution 2 per cent. and 8 per cent. of common salt. Two cubes $2\frac{3}{8}$ inches in the side, and two pieces of brick cemented together, were prepared with each of the mortars, and allowed to set in the open air at temperatures ranging at night from 24°·8 Fahrenheit to 17°·6 Fahrenheit, rising in the daytime to a little above the freezing point. The following was the result of the trials:—

The specimens prepared with fresh water fell to pieces under the pressure of the hand, and the bricks did not adhere to each other.

The specimens prepared with water containing 2 per cent. of salt could not be crushed by hand, and the bricks required some effort to separate them.

Lastly, the samples made with water containing 8 per cent. of salt could only be destroyed by the aid of a hammer, and the bricks could not be separated. In all cases the Portland-cement mortar proved stronger than that made from hydraulic lime.

Experiments still more interesting were communicated to the American Society of Civil Engineers by Mr. A. Noble.[1] The construction of the locks on the St. Mary Canal, between Lakes Superior and Huron had to be stopped at the end of October on account of the frosty weather. Towards the close of 1877 the works were carried out with Portland-cement mortar and with good natural American hydraulic lime, both mixed in the proportion of one of lime to one of sand. The work built with Portland cement turned out to be perfectly sound when examined the following year, but the hydraulic-lime mortar had been destroyed to a depth of between 3 and 4 inches. In the month of February some concrete was laid in frosty weather, and although a good deal of salt was used the mass was completely frozen, notwithstanding which it proved perfectly sound in the end, and resisted a head of 15 feet of water without allowing any to leak through.

Four piers were built for a bridge over the St. Louis, near Duluth. During the construction of the first pier the temperature

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[1] Transactions of the American Society of Civil Engineers, March 1887, p. 79.

varied between 1°·4 Fahrenheit and 21°·2 Fahrenheit; during the building of the second pier the temperature was about 20°, and the remaining two were built where the thermometer stood above the freezing-point. For the face-work Portland cement mortar mixed with sand in the proportion of 1 to 1½ was used, and for the interior work 1 to 2½. The sand was warmed, and large quantities of salt were added to the water, yet at 1°·4 Fahrenheit the mortar froze very quickly while it was being used. In the end no difference could be discovered between the quality of the masonry in the first and last piers.

Mr. G. S. Morison, at the construction of a bridge over the Omaha during the winter of 1885, made some test specimens out of Portland cement and native American hydraulic lime. The samples were kept in the air for twenty-four hours, then plunged under water. Cold weather coming on, the water was frozen into a solid mass of ice, and, on its melting again, the Portland cement specimens appeared uninjured, while the samples made out of the native hydraulic lime fell to pieces.

Mr. Shanahan, superintendent of Public Works of the State of New York, states that he builds walls summer and winter, but in cold weather he uses a larger proportion of cement, and adds a strong solution of salt for mixing the mortar; he has never found that defective work has resulted from this practice. It by no means follows that sea water would be suitable for mixing mortars, because sea water contains a considerable proportion of the salts of magnesia.

W. A.

On Cast-Iron for Mechanical Purposes. By Ed. Deny.

(Bulletin de la Société Industrielle de Mulhouse, 1887, p. 309.)

In this Paper the Author treats in great detail the subject of cast-iron, with the view of obtaining an insight into the principles that govern the choice of mixtures that will give the best results in practical work.

The Author points out that whereas a tensile strength of from 10 to 12 kilograms per square millimetre (6½ to 7½ tons per square inch) was formerly an average resistance for iron run direct from the blast-furnace, at the present time mixtures are run at the second melting, which easily show a breaking tensile-stress of 14 to 15 kilograms (9 to 9½ tons), and these latter figures have been far surpassed in America, where cast-iron has been obtained which has a breaking tensile-stress of 32·275 kilograms per square millimetre (20½ tons per square inch), and Gruson of Buckau, and Ganz of Buda-Pest, have secret mixtures, which possess an extraordinary tenacity and chill perfectly. They produce the so-called Hartguss.

The property of chilling that Hartguss possesses has given rise to a great confusion of ideas, and has caused the other remarkable

properties of this material to be neglected. This has led other foundries to give the same name to mixtures made with ordinary chilling-iron that can only discredit the true product.

Tough cast-iron should be moderately carburated, and should contain some manganese, a little silicon, and only traces of sulphur and phosphorus. It is almost impossible to define the proportions in which these elements should be present, because they may vary considerably without altering the strength, although the slightest variation in the amount of foreign matter materally affects the properties of the mixture. Besides the carbon, manganese, silicon, sulphur, and phosphorus, there are other ingredients which appear in cast-iron, though less often, such as arsenic, copper, and titanium, and others, as aluminium, potassium, magnesium, and calcium, which often figure in old analyses, and are present in small quantities more often than is supposed.

The opinion has been held by some that the best results should be obtained by using a cast-iron that contains only iron and carbon; others again have held that other ingredients might be present up to 10 per cent. of the whole without rendering the metal improper for use. The Author remarks that his investigations show that both these views are erroneous, although the first opinion might possibly be correct if it were possible to obtain chemically pure carbon and add it to chemically pure iron, and the second might be correct if the foreign ingredients were added in just the necessary proportions to neutralize one another.

The true worth of any given cast-iron can only be ascertained by direct physical tests, which give results of much more value than those obtained by analysis. The usual physical tests are those of tension, bending, or impact, but to give a complete insight into the properties of an iron, it ought to be tested for hardness as well. It is not unusual to find a cast-iron considered unsatisfactory that will stand tensile bending and impact tests much better than an iron that is more highly prized because it is easy to work and runs sound castings.

The Author next discusses the various pig-irons in use from No. I to No. VI, as the quality passes from a dark iron with flakes of graphite through grey to mottled, and then white iron, and he gives the mean analyses of different numbers of three sorts, viz., Esch (Luxembourg), Creusot, and Terre Noire, as on page 419.

During its formation cast-iron dissolves more carbon the hotter it is, and the excess is precipitated during cooling. This excess forms scales of graphite, which results in a multitude of soft and weak points being distributed throughout the mass. In consequence of this, graphitical iron is soft and weak. On the other hand, combined carbon, as is well known, when totally dissolved and present in several units per cent. renders the metal brittle and as hard as tool-steel. In foundry practice, both these extremes are to be avoided, and the endeavour should be to obtain a metal which is strong and yet soft enough to be utilized.

	Esch.						Creusot.					Terre-Noire.				
	I.	II.	III.	IV.	V.	VI.	I.	II.	III.	IV.	V.	I.	II.	III.	IV.	V.
Iron	91·86	92·66	93·05	94·27	94·36	94·78	92·4	92·97	93·02	93·70	94·0	92·17	92·98	93·85	94·58	94·15
Graphite . . .	2·99	2·69	2·58	1·67	..	..	..	..	..	..	..	3·25	2·55	1·95	1·15	0·85
Combined carbon.	0·34	0·39	0·44	1·2	..	..	..	..	..	..	..	0·94	1·23	0·04	2·08	2·17
Total carbon . .	3·33	3·08	3·02	2·87	2·92	2·59	3·45	3·21	3·19	2·95	2·99	4·19	3·78	1·99	3·23	3·02
Silicon . . .	2·52	2·19	1·63	0·74	0·52	0·42	2·75	2·54	2·40	2·10	1·81	2·25	1·95	1·75	1·15	0·85
Manganese . .	0·49	0·38	0·29	0·18	0·11	traces	0·54	0·56	0·59	0·54	0 39	1·25	1·05	0·95	0·65	0·58
Sulphur . . .	traces	traces	0·09	0·19	0·32	0·49	0·07	0·07	0·08	0·10	0·12	0·02	0·04	0·06	0·07	0·09
Phosphorus . .	1·80	1·80	1·83	1·75	1·77	1·72	0·77	0·63	0·71	0·61	0·68	0·05	0·05	0·05	0·04	0·04

The Author investigates this question at length, and, by plotting the results of tests as curves, shows that the maximum of strength is attained with a mixture in which the amounts of graphite and carbon are nearly equal, or the combined carbon slightly in excess of the graphite. Such a mixture produces a mottled iron—neither grey nor white. From this it results that grey iron can be strengthened either by reducing its proportion of graphite or increasing its proportion of combined carbon; and white iron may be strengthened by increasing its percentage of graphite or lowering its percentage of combined carbon.

The condition in which carbon exists in cast-iron is not only determined by the temperature at which fusion has been effected, but also by the circumstances under which the iron has solidified. Rapid solidification favours the retention of carbon in the combined state, and by this means it is possible to convert grey cast-iron, if only slightly siliceous, into iron that is perfectly white. This is the principle which governs chilling.

All grey pigs do not chill, and those resist this alteration most which contain most silicon, and those chill best which have a mottled texture.

After carbon, silicon is the most useful ingredient in cast-iron, and it is always present in proportions varying from 0·2 per cent. up to 30 per cent. in ferro-silicon. Silicon requires a very high temperature for its reduction, and is more abundant in hot-blast than in cold-blast iron.

The Author treats of silicon at considerable length, and calls attention to the efforts which have been recently made to rehabilitate silicon, and to show that, provided the silicon present does exceed a definite amount, that, far from reducing the strength of the iron, it serves to increase it. The Author discusses the researches of Mr. Riley, Mr. Stead, Mr. Wood, and Mr. Turner on this subject, and gives an abstract of the experiments made by the latter; but he considers that the results obtained were due more to the relative purity of the irons used and their slight carburization than to the amount of silicon contained in them.

The characteristic of manganese is to dissolve graphite and to increase the amount of combined carbon. It also augments the faculty for chilling; but in an iron containing 3·5 to 3·8 per cent. of carbon (which amount of carbon always is accompanied by 1 to 1½ per cent. of silicon) manganese dissolves very little graphite unless present in larger quantity than ½ to 1 per cent. The effect of the simultaneous presence of manganese and silicon is undoubtedly reduced by their combining together and forming a distinct alloy dissolved in the iron. Thus there are examples of iron containing 6·5 per cent. of silicon, 7 per cent. of manganese, and 3·25 per cent. of carbon, which chill only very slightly. Manganese and silicon may therefore be considered as antagonistic, and either may serve to correct an excess of the other.

As manganese tends to dissolve graphitic carbon it ought to harden the iron to which it is added, and to increase the strength

provided that it is not added in more than sufficient amount to bring the graphite and combined carbon to the best proportions.

Phosphorus, like manganese, gives fluidity to iron without sensibly lowering its melting-point. Experiments have shown that 0·4 per cent. of phosphorus renders iron brittle, but this influence is not felt until the amount of phosphorus present exceeds 0·2 per cent., because some of the iron formerly reported to be the best for artillery in France (*e.g.*, that of Bandiat and of Pont-Nau in the Landes) contains phosphorus to this extent. Phosphorus hardens iron and tends to make it white, not only by its action on the condition of the carbon, but also directly.

Sulphur dissolves in iron to an unlimited extent, until the iron passes into the condition of sulphuret of iron. Its action is always noxious. It increases the fluidity of the iron, but makes it set quickly with a great deal of "draw"; it gives a dull, pale grain, and makes the iron spongy and brittle. There are few ores or fuels which do not contain sulphur, and the only way to prevent it getting into the iron is to use a basic flux. Without being completely incompatible with carbon, sulphur diminishes the affinity of iron for it. A very sulphurous iron is never rich in carbon, and, *vice versâ*, a very graphitical iron is never rich in sulphur.

According to the experiment of Mr. Caron, metallic manganese by simple fusion with cast-iron deprives it of a large portion of its sulphur, and Mr. Ponsard asserts that 80 to 90 per cent. of the sulphur may be got rid of by stirring ferro-manganese into the ladle at the moment of running. The sulphur passes into the slag, 2·6 parts of manganese being required to 1 of sulphur.

The Author next considers the question of the softness of cast-iron, and after discussing the tests previously in use for measuring this quality, he proceeds to describe a simple and scientific method that he uses. A small grindstone furnished with a counter is fitted up with a lever, which presses a test-piece of a given size against the rim of the wheel with a definite force. *Cæteris paribus* the softness of the iron may be considered to be directly proportional to the amount ground away by a given number of revolutions. A scale of softness is made by taking a very soft brand of iron (say Coltness No. 1), and denominating this No. 10 on the scale, a piece is then tested in the mill, the cubical loss and the number of revolutions being noted; on any other iron being tried a simple proportion will give its place on the scale, absolutely hard iron being zero.

The Author then considers some other properties of cast-iron, a prominent one being the contraction on cooling which varies from $\frac{1}{10}$ inch to $\frac{1}{4}$ inch per lineal foot, a usual amount being $\frac{1}{8}$. Very excessive contractions are only met with in white iron or steel. Besides contraction, cast-iron, after being run into the mould, undergoes a molecular shrinkage or "draw" (*tassement*), which is the more pronounced the heavier the casting. This "draw" probably arises from shrinkage of the iron during the liquid state,

and doubtless also from gas, air, or decomposed vapour of water, which the iron has absorbed during fusion or running, this is disengaged during solidification, forming cavities or "draw holes" in the interior of massive pieces.

Different iron has different degrees of "draw," according as it contains more or less carbon or sulphur, and perhaps other ingredients which may act on this property; the Author therefore considers that for a complete study of any iron it is necessary to test it for "draw," which he does by filling a small open chill of a standard size, and after setting measuring the surface-depression. The Author uses an open chill 80 millimetres diameter and 62 millimetres deep, with a globular bottom; this chill weighs 15 kilograms and holds 5 kilograms of iron. This test serves at the same time to test the chilling-property of the iron; and the chilling-action also serves to exaggerate the surface sinking, which for comparative purposes is an advantage.

The Author treats at some length of the whole subject of chilling; he shows that a chill should as an average be about three times the weight of the casting. He considers that a deeper chill than 1 inch should not be attempted, and also strongly deprecates running chilling-iron too cold, as he shows by experiment that although this somewhat deepens the chill it much weakens the iron. This weakening effect of running too cold is even more marked with iron run into sand; the experiments showed a loss of 28 per cent. of strength with iron run into dry sand and 17 per cent. with iron run into a chill, as contrasted with the same metal run much hotter.

The latter part of the paper deals in great detail with a series of experiments made by the Author in order to determine the effect of adding different ingredients to mixtures with a view of improving the strength.

The first set of experiments consisted in testing a series of mixtures made by adding a constantly increasing amount of steel cuttings to a No. III manganiferous hematite pig. The pig came from Wetzlar in Nassau, and was smelted from a combination of red hematite and brown manganiferous ores. The analysis of the pig was:—Total carbon 3·5, silicon 2·15, manganese 2·5, phosphorus 0·36 per cent. The steel-cuttings were made from rolled puddled-steel bars. The successive percentages added in this, as in all the other series of experiments, were 10, 20, 33·3, and 50 per cent. The test bars were tested by tension, bending, impact and for softness; in the present series the softness gradually diminished in the proportions 9·2, 9·1, 8·6, 3·4, 1·17 per cent., the latter being with 50 per cent. of steel.

Series No. 2 of tests consisted in substituting the phosphoric Esch, pig No. II, of which the analysis was given above for the No. III hematite.

Series No. 3 was obtained with the hematite pig and spiegeleisen instead of steel-clippings.

Series No. 4 consisted of Esch pig and spiegeleisen.

Series No. 5 was obtained with the hematite pig and ferro-silicon instead of steel or spiegeleisen.

Series No. 6 consisted in mixing the Esch pig with ferro-silicon. The results of the whole of the twenty-four mixtures tried are plotted as curves, and these curves are compared with one another, showing in a very graphical manner the effect of the different additions.

All the experiments are discussed at length, and the Author summarizes his results as follows:—

1. Ordinary grey pig may be much improved by partially decarburizing it by mixing it with steel (or even white iron) in quantities just sufficient to attain that mottled condition which gives the greatest strength, the improvement in strength must however be obtained at the expense of softness.

2. Hematite can be thus improved much more than phosphoric pigs.

3. For an equal percentage of increase in strength phosphoric pig is much more hardened than hematite.

4. The addition of spiegeleisen either to the hematite or phosphoric pig is prejudicial to the resistance to tension and impact, but by it the resistance to bending may be slightly improved.

5. The addition of ferro-silicon to either kind of pig lowers the resistance to tension, and is very prejudicial to the resistance to impact, but it may slightly raise the resistance to bending.

6. Ferro-silicon has the advantage of considerably softening the iron to which it is added, and may in many cases be very usefully employed for producing this result, but its use for the purpose of bringing white iron back from No. V or No. VI to No. III or No. IV is not, in the Author's opinion, to be recommended.

The Author proposes at a future date to undertake and publish a further series of experiments, in order to see if a beneficial result may not be obtained by increasing the amount of manganese by adding spiegeleisen, or the silicon by adding ferro-silicon whilst simultaneously decarburizing by adding iron or steel.

W. P.

[Note.—The French method of testing used by the Author appears in many ways more rational than many of the English methods. The bending tests were made in Monge's apparatus on bars measuring 40 × 40 millimetres (1·57 × 1·57 inch) in section. This section is a better section than the English 2 inches × 1 inch, as it is less affected by surface or "skin" conditions, whilst the resistance to bending is almost identical. In Monge's apparatus the test-piece is acted on as a cantilever, and the strength or resistance R is obtained from the formula $\frac{R\,h^3}{6} = P\,L$, where h is the side of the square bar (40 millimetres), P the breaking-load and L the length of the lever. The impact-test used in France is that of dropping a monkey weighing 12 kilograms (26½ lbs.) on a 40 × 40-millimetre bar, placed on knife-edges 160 millimetres (6·29 inches) apart, on an anvil weighing 300 kilograms. The first drop should be 20 centimetres, rising 20, 22, 27, 30, &c., until fracture occurs.—W. P.]

On the Strength of Iron Structures for Buildings, in Compression at High Temperatures. By M. Möller and R. Lühmann.

(Verhandlungen des Vereins zur Beförderung des Gewerbfleisses, 1887, p. 573.)

In response to the offer of a prize by the society of which the above journal is the organ, the Authors undertook the experiments which form the subject of this Paper. The experiments were chiefly directed towards investigating the behaviour of wrought- and cast-iron columns when heated on one side only under compression, and the best means of protecting them from the influence of fire.

To ascertain the different manner in which wrought- and cast-iron are affected by heat, five pairs of test-pieces were prepared, each pair being of the same dimensions, but of different materials; the proportions of the various pairs differed from each other. Similar experiments were made on each test-piece at the normal temperature, and also when heated.

To determine the influence of various forms on the strength of iron columns, twenty-four pairs of test columns were made; each pair was of the same material and sectional area, but the two members of a pair differed from each other in one of their proportions. Sixteen pairs were tested in fire, and eight at the normal temperature.

To test the effect of hinged ends on the strength of columns as compared with the results obtained when the ends rest against nearly parallel surfaces, two pairs of test-columns were employed; the two columns of each pair were alike in dimensions and material, but were differently connected to the testing-machine.

To ascertain the influence of a lagging or jacket in protecting iron columns from the action of fire, three pairs of the latter were prepared; the two pieces of each pair were in every respect alike, but one was tested with, and the other without a jacket.

These jackets for protecting the metal from the action of the fire consisted of a mixture of 1 part cement with 3 parts sand.

The behaviour of columns of masonry, and that of wooden posts was investigated in each case on four samples.

Both hollow and solid columns of cast- and wrought-iron were employed in the experiments; the hollow columns had 150 millimetres (5·9 inches) outer, and 120 millimetres (4·72 inches) inner diameter; the cast-iron columns were 1, 2, and 4 metres long, the wrought-iron columns, 1 and 2 metres.

The solid cast-iron columns were 9 centimetres in diameter, and those of wrought-iron were specified to be of the same size, but were, in fact, slightly less, the sectional area being only 62 square centimetres (9·61 square inches), instead of 63·6 (9·858 inches); these columns were also made in lengths of 1, 2, and 3 metres (3 feet 3·37 inches, 6 feet 6·74 inches, and 9 feet 10·11 inches).

In addition to the round columns, three wrought-iron columns,

built up of bars, angles, and plates, 150 millimetres (5·9 inches) square, were also prepared for comparison with the former.

The pillars of masonry tested were built up of slabs of paving-stone, 22½ by 22½ centimetres (8·85 by 8·85 inches), and had a length of 2 metres (6 feet 6·74 inches). In one pillar, two cubes, one of sandstone, and the other of granite, were inserted.

The four wooden posts used in the experiments had a section of 15 by 15 centimetres (5·9 by 5·9 inches), and a length of 2 metres (6 feet 6·74 inches) each.

The tests were made with a hydraulic testing-machine, having a ram 508 millimetres (20·01 inches) in diameter. The fire for heating the test-pieces was made in a rectangular wrought-iron trough, partially inclosing the former. The fuel used was coke and wood.

The temperatures were measured by pieces of lead and an alloy of silver and lead, the melting-points of which were known; in each case the test-piece was heated on one side to the temperature at which the silver alloy melted—a clearly visible red-heat—about 600° Centigrade, on the other side to the melting temperature of lead, about 330° Centigrade.

All the cast-iron columns, when heated, were cooled by jets of water from different sides, but none of them cracked under this treatment, with the exception of one which broke under pressure. In the case of similar experiments previously carried out by Professor Bauschinger, all the cast-iron columns cracked, and the Authors ascribe this difference in results to the fact that the test-pieces used by himself had all been recently cast, while those of Professor Bauschinger were old, and possibly of inferior material. The following are some of the more important conclusions arrived at by the Authors: In the case of stiff columns—with a low proportion of length to diameter—the ratio of the strength of those of cast-iron to those of wrought-iron, when heated, was about the same as when cold. For slender columns, both materials were about equally strong when cold, but cast-iron was somewhat superior to wrought-iron when heated. The destruction of both cast- and wrought-iron columns in the fire was always due to bending. The deflection of stiff columns resulted from the compression of the heated side, was consequently away from the fire; with slender columns, the opposite occurred, the deflection being the result of the expansion of the heated side, and therefore, towards the fire. The formula of Laissle and Schübler, for the strength of columns subject to buckling, gives loads for cast-iron which can also be borne when the metal is heated, but the Authors recommend the use of a coefficient K, somewhat higher than that usually employed. The formula in question is—

$$P = 1{,}000\ F \frac{1}{1 + K \frac{l^2\ F}{J}},$$

where P denotes the load carried, F the sectional area of the

column, l its length, J the moment of inertia of the section, and K the coefficient previously mentioned, the units being the centimetre and kilogram. For K, Laissle and Schübler give the value 0·00023, while the Authors recommend 0·0004.

By protecting iron columns with suitable jackets, the destructive action of fire may be delayed for several hours.

Pillars of paving-stone are practically uninjured by fire, while sandstone and granite are destroyed; granite, when subject to a red-heat, disintegrates into pieces which may be pulverised between the fingers.

The pressure on the ends of the columns was applied eccentrically, the eccentricity being 1 centimetre (0·39 inch), as in this manner the inaccuracies occurring in practice were considered to be allowed for.

The original is accompanied by illustrations, and contains full details of the experiments and calculations at great length.

G. R. B.

Compressive Strength of Steel and Iron. By C. A. Marshall.

(Transactions of the American Society of Civil Engineers, August 1887, p. 53.)

The experiments which form the basis of this Paper were undertaken with the object of discovering the relation of the compressive and the tensile resistance of steel and wrought-iron to each other. The specimens for testing consisted of solid rolled bars as they came from the rolls.

The results of the tests clearly show the relation sought; and they indicate that the elastic limit of the material is the chief factor in determining the ultimate resistance of struts of iron or steel, of ordinary length, excepting the very hardest kinds; seeing that the two quantities, elastic limit in compression, and ultimate compressive strength, are identical, within a considerable range of length-ratio of columns. Again, when a load equal to the elastic limit of strength is imposed, and allowed to remain for some time, it causes permanent change of length—more than is generally understood—and apparently a definite quantity for each case. The change of length, after having commenced under a load equal to the elastic limit, will continue under a less load. It is demonstrated in the cases of the 100,000-lb. steel, the 67,000-lb. steel, and the hard iron made from scrap, that the total change of length is effected equally well, though it requires greater length of time, with a load 1000 lbs. or 500 lbs. less than that due to the elastic limit, as with a load due to this limit. This conclusion is clearly sustained by the diagrams of strains. In the same time, the lesser loads cause less alteration of length. The stretch at the elastic limit is, according to the tension-diagrams, as follows:—

	Per cent.
For the 100,000-lb. steel	0·3
„ 80,000 „	1·4
„ 67,000 „	1·85
For hard iron	1·3
„ soft „	2·3

In compression, the permanent stretch appears to vary from near equality to that from tension, to about half as much. The soft iron shows nearly equality; the hard iron considerably less; the steels, except perhaps the 80,000-lb. steel, nearly equality. The detail test-reports, Tables 10 to 13, supply the following accurate comparisons of permanent change of length:—

		Per cent.
Steel, W	In tension	2·11
	In compression	2·05
Iron, K	In tension	1·38
	In compression	0·57

The specimens under compression reach their maximum change of length under constant load in less time than those under tension.

The progressive scalings, or breaks in continuity of the roll-scale, of specimens under test is curious and instructive. In the case of steel, the scale stretches without breaking up to the elastic limit; but it breaks under any stretching approaching one-half per cent. The roll-scale on iron appears to be more brittle than that on steel, and sometimes it begins to drop off before the elastic limit is reached. The permanent change of length is shown by the behaviour of the scale to be local and progressive. The scaling can be watched as it progresses from the ends of a specimen, whether under tension or compression, towards the middle; and it has been proved micrometrically, that the middle portion of the piece does not undergo any permanent change of length so long as the roll-scale on it remains unbroken. So soon as the progressive scalings from the ends meet at the middle of the length of the specimens, the whole attainable stretch is achieved.

The Paper contains seventeen tables of results of tests, and eight plates of test-diagrams, giving details of tests under tension and compression, with an Appendix containing detail-reports.

D. K. C.

Strength of Ropes. By A. Duboul.

(Bulletin de la Société d'Encouragement, Paris, 1887, p. 689.)

The Author has experimentally investigated the quality of workmanship, the strength, the extension, and the elasticity of ropes and cables, round and flat, of hemp, of aloe, and of iron and steel wire. The apparatus, constructed in 1880, for these investigations consists of a horizontal hydraulic press, and a steelyard of three levers, with a sliding weight on the last, by which resistances

of from 1 to 60,000 kilograms, or 60 metric tons, can be measured. Higher pressures, up to 100 tons, are indicated by means of a pressure-gauge on the body of the press. Specimens submitted for trial are fastened by winding each end of the rope on a grooved pulley, specially designed, the extremity being knotted and secured against a fixed edge in the groove. The power is applied by means of a ring applied to a separate edge in the groove. The piston of the press is 11·81 inches (300 millimetres) in diameter, and that of the piston-rod is 4·33 inches, with a maximum stroke of 31·5 inches. The pressure is about 100 atmospheres. The useful length of cable for testing is about 13 feet. The weight of the apparatus, exclusive of the pump, is $7\frac{3}{4}$ tons.

Ropes and cables, of white hemp and tarred hemp, were procured for testing, imported from Italy and Russia, in addition to those obtained in France, of long fibre, handspun, with from fifty to fifty-five twists to the yard; $1\frac{1}{2}$ yard of rope-yarn sufficed to make 1 yard of cable. A selection of results of testing, for elongation and tensile resistance, is given in the annexed Table.

Results of Tests of Ropes.

		White Hemp.		Tarred Hemp.		White Manilla.		White Aloes.	
Circumference before rupture	inches	4·33	4·33	4·25	4·25	3·94	3·94	4·33	4·33
Circumference after rupture	„	3·86	3·74	3·70	3·74	3·27	3·39	3·54	3·66
Length tested	feet	32·8	32·8	32·8	32·8	32·8	32·8	32·8	32·8
Length measured for testing elongation	„	13·1	13·1	13·1	13·1	13·1	13·1	13·1	13·1
Elongation	inches	27·2	28·3	25·6	26·4	23·2	22·8	26·0	26·8
Section of the four strands	sq. ins.	0·819	0·819	0·819	0·819	0·819	0·819	0·819	0·819
Section of the piece		1·490	1·490	1·481	1·481	1·246	1·246	1·491	1·491
Resistance	tons	7·94	7·43	5·22	5·64	5·44	5·96	3·99	4·45
„ of the four strands per sq. in.	„	9·78	9·02	6·35	6·86	6·60	7·24	4·83	5·40
Resistance of the piece per sq. in.	„	5·27	4·95	3·49	3·87	4·32	4·76	2·67	2·98
Weight of the whole piece tested	lbs.	17·4	17·6	18·7	19·6	15·0	15·2	15·0	15·4

The results of many tests of flat tarred ropes have given a mean strength of from 3·43 tons to 3·75 tons per square inch, rupture taking place at the points of attachment. The elongation rarely exceeds from 5 to 6 per cent.

From all the results of testing, the average ultimate tensile strength of rope was as follows:—

White hemp	4·76	tons to	5·08	tons per sq. in.
Tarred hemp	3·54	„	3·81	„	„
White manilla	4·44	„	4·76	„	„
White aloes	2·54	„	3·17	„	„
Flat ropes of tarred hemp or tarred manilla	3·54	„	3·81	„	„

The results of practice show that round ropes and cables may be worked, with but moderate attention, at a stress equal to one-third of the breaking-stress, and flat ropes one-fourth. In ordinary industrial practice the proportion is often but from one-sixth to one-eighth.

Ropes made from esparto and cocoa fibres have an ultimate resistance of from 1 ton to $1\frac{1}{4}$ ton per square inch.

With regard to ropes and cables of galvanized charcoal-iron wire, it is estimated that the equivalent of hemp cables has two-tenths of the diameter of the latter for unannealed wire, or three-tenths for annealed wire. The rope of unannealed wire has an ultimate strength of from 25·4 tons to 31·7 tons per square inch of section of metal, from 7 to 9 per cent. of elongation, and from 1 to 2 per cent. of elasticity. The rope of annealed iron has an ultimate strength of from 22·2 tons to 25·4 tons, an elongation of from 12 to 15 per cent., and from 3 to 4 per cent. of elasticity. The galvanized wire, tested by itself, yields 10 per cent. more resistance to breaking than in the form of rope.

Wire ropes for mining-service, of the first quality, have an ultimate strength of from 40 to 45 tons per square inch of metal section.

According to one system of testing wire, it is strained to one-tenth of its total resistance, and is exposed to the fall of a weight of 2 kilograms, or about $4\frac{1}{2}$ lbs., from a height of from 5 feet to $6\frac{1}{2}$ feet. It withstands from eight to ten falls before rupture.

The foregoing results differ sensibly from those formulated elsewhere.

From the results of numerous experiments, it is found that cast-steel wire ropes stretch from 4 to 6 per cent. before rupture, with an elastic limit of from 2 to $3\frac{1}{2}$ per cent. Such ropes bear three-fourths of the breaking stress before exhibiting any signs of failure. The Author is of opinion that, as iron has superseded hemp as the material of standing ropes, so iron will be superseded by steel.

D. K. C.

Composite Iron and Brick Chimney at Rocourt. By — GUÉNOT.

(Dingler's Polytechnisches Journal, vol. cclxvii. 1888, p. 194.)

The particular construction of the chimney described in the above article was determined by the nature of the ground on which it had to be built, a loose soil rendering a light structure necessary. The flues leading into the chimney were formed in the foundation, the latter resting on a bed of concrete. From the foundation four upright lattice-girders were carried up and connected together by cross-bracing. The inner edge of each girder was made upright, and the outer edge inclined, each girder being narrower at the top than at the base. On the inner edge of the skeleton frame thus formed by the four girders and bracing,

the shaft, or chimney proper was formed, by specially moulded bricks or tiles about 5 inches in thickness, with rebated or lapped joints; angle-iron bands were introduced at intervals to bind the whole firmly together; the girders were bolted to a cast-iron base-plate resting on and bolted down to the foundation by long bolts. The total height of the chimney was 140 feet, and the inside diameter 8 feet 6 inches. The whole chimney was erected in thirty-nine days; the ironwork in thirty-one days, and the remainder in eight days. The total weight of the structure is given as 543 tons, giving a pressure per square inch on the foundation of nearly 17 lbs. A chimney of the same height and size, built wholly of brick, is estimated to weigh rather more than twice as much, giving a pressure per square inch on the foundation of about 33 lbs. The chimney described was built ten years ago, and has stood the strain of many storms; the cost is stated to have been 19,200 francs, and that of a brick chimney of the same height and size to be about 14,300 francs. The construction of the chimney is shown in the illustrations which accompany the article.

H. H. P. P.

The Austrian Prototype of the Forth Bridge. By — Köstlin.

(Wochenschrift des österreichischen Ingenieur- und Architekten-Vereines, 1888, pp. 63, 64.)

This Paper is a continuation of that by Mr. Gärtner (published in No. 4 of the Wochenschrift for 1888) on the "System of Construction of the Forth Bridge," where reference is made to a previous report by that gentleman, in which he had advocated the claims of Gerber and Professor Ritter to be considered the inventors of this system. Since the publication of that report, however, it appears that Mr. Gärtner's attention had been drawn by Professor Gerlich, of Zurich, to the works of the Austrian engineer, Josef Langer (1859–73), and especially to his treatise on the "Theory of Compound Bridge Systems," in which is described a "stiffened suspension bridge with vertical anchorage" as designed for a span of 656 feet, but adapted for much larger spans, which has, it is said, a striking resemblance to the cantilever system of construction of the Forth Bridge, but a committee (consisting of Messrs. Hermann, Köstlin, Humbortel, Fink, H. Schmid, and Winkler), appointed by the Austrian Engineer and Architects' Association in 1872, reported unfavourably of Langer's system, and pronounced it to be based on incorrect principles. Since the claim advanced in favour of Langer as the inventor of the system employed in the Forth Bridge could not be sustained, Mr. Köstlin, in the Paper now under notice, endeavours to show that the germ of the noble Forth Bridge was developed on Austrian soil, and he finds this in Carl von Ruppert's design in 1860 for a bridge over the Bosphorus at Constantinople, an elevation of which is given

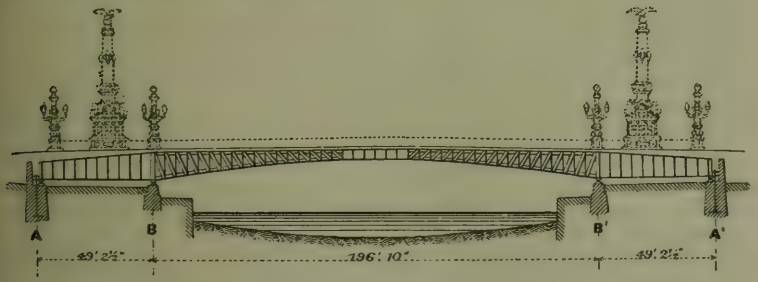
showing a central span of 676 feet, and two side spans of 533 feet each. He then traces in detail the resemblance in the chief constructive features of the two bridges, and concludes by declaring that "the Bosphorus bridge by Ruppert is indeed—not the model—no—but absolutely (and more decidedly than Langer's 'stiffened suspension bridge') the true prototype of the Forth Bridge, and was indeed developed on Austrian soil."

W. H. E.

Stephanie Bridge over the Danube Canal in Vienna.

(Allgemeine Bauzeitung, 1887, p. 81.)

This bridge is of an original and bold design in point of engineering, and a remarkable one in point of architecture and ornamentation. As shown in the figure, it is designed on the principle of a beam fixed at both ends, but more correctly of a continuous girder on four supports, the outer shorter spans being so heavily weighted that, in the most unfavourable case of loading, there is still a pressure of 21 tons on each of the bearings A and A^1. An anchorage is nevertheless provided for at both points, to act in case it should be necessary at any time to remove a portion of the balance-weight. B^1 is a fixed pivot-bearing; while A, B, and A^1 are pivot-bearings on rollers.



The friction of the rollers represents an appreciable force, which produces bending-moments in the girder and in the masonry block, and it was accordingly introduced into the calculation of the strength of these parts.

The dead-load of the middle span is 466 lbs., and the assumed moving-load 94 lbs. per superficial foot. With these loads, the main-girders are strained with 5·7 tons; the cross-girders with 5·08 tons, and the rivets with 3·81 tons per square inch. A load of 14 tons, on a wheel-base of 11 feet 6 inches by 5 feet, was also taken into account.

The width of the bridge is 63 feet 4 inches, divided by eight girders, about 7 feet 9 inches apart. The cross-girders are 5 feet apart, and on them are trough-irons, laid longitudinally, which

support the concrete and wood-block pavement. The balance-weight in the short spans of the girder is constructed of rails and granite blocks.

The engineer is Mr. Oswald Liss, and the architect Mr. Otto Hieser.

M. A. E.

The Moltke Bridge in Berlin. By — Pinkenburg.

(Deutsche Bauzeitung, 1887, pp. 37, 49.)

This bridge, formerly known as the Unterspree Bridge, was orginally constructed in 1864–65 by the Niederschlesische-Markische Railway on the site of a timber structure; it is now one of the most important in Berlin, as it connects the Moabite district with the southern quarters of the city, and is in close proximity to the new goods station.

The Paper gives a description of the bridge as originally erected, of its gradual failure, and final replacement by the present structure. It crosses the River Spree at an angle of 81°, where the stream is about 180 feet wide. The particulars of the original structure are as follows, viz.: There were five arched spans, three being across the stream and one at each end spanning the Frederick-Carl and the Crown Prince Roadways on the left and right banks respectively. The river arches were each 53 feet 9 inches at springing level, and those over the roadways 41 feet 8 inches span, the rise being in all cases one-twelfth of the latter.

The arches were of wrought-iron, hinged at three points, viz., at the springings and crown, and were the first constructed in Germany on that system. The arch-members were each formed of two vertical plates, $3\frac{7}{8}$ inches apart, with angle-bars riveted to their top and bottom outside edges, connected together horizontally by lattice-bars, their depth diminished from 1 foot $2\frac{1}{2}$ inches at the springing to 1 foot $0\frac{3}{8}$ inch at the crown. The horizontal main-bearers were each formed by a pair of channel-irons $3\frac{1}{8}$ inches deep, and directly supported the cast-iron floor-plates $\frac{3}{8}$ inch in thickness, strengthened with 4-inch feathers. The verticals and diagonals of the spandril filling were of channel-irons, the semi-span being divided by the verticals into six bays, each of 4 feet $4\frac{3}{8}$ inches, and all these bays being braced with a single diagonal, except the two next the crown, which were left open. The above-mentioned hinged joints were formed by cast-iron turned bolts, the diameter of those for the river-openings being $6\frac{1}{8}$ inches, the metal being $2\frac{1}{4}$ inches thick. The bridge carried a roadway 25 feet 9 inches broad, a single line of rails (4 feet $8\frac{1}{2}$ inches gauge), the formation width being 13 feet $4\frac{1}{2}$ inches, and footways on each side 5 feet 4 inches and 6 feet $10\frac{1}{2}$ inches broad, or a width altogether of about 50 feet. Each span was made up of fourteen arch-members, those under the railway track being

stronger than the others, and their distance apart only 3 feet $3\frac{3}{8}$ inches instead of 4 feet, as elsewhere.

The piers were of brickwork, with dressed granite facings; the breadth of the river-piers was 7 feet 1 inch at springing level, and 9 feet 4 inches above the footings, the latter resting upon brickwork 1 foot deep, laid without mortar or cement, within sheet piling; the height from the foundations to the arch-springing level was about 24 feet 7 inches.

In calculation, the assumed moving-load for the roadway was $102\frac{1}{2}$ lbs. per square foot, and a dead load of $230\frac{1}{2}$ lbs. per square foot; and for the rail-track a moving-load of 1·41 ton, and a dead load of 0·09 ton per foot run.

Early in the year 1866, the bridge having been completed and opened for traffic in the preceding August, an unusual wavy appearance showed itself in the roadway near the crown of some of the arches, which led to the structure being carefully watched and levels taken from time to time, and also tested with special loads run over the rail track and roadway.

The trials proved that a subsidence had taken place in the crown of the middle river-span, and an elevation of that of the left bank river-span; also the river-piers showed signs of weakness, appearing to sway slightly under the moving load.

The observations were continued, and again reported on in the ensuing year 1867, but as the amount of abnormal elevation and depression of the arch crowns did not appear to be much increasing, no further investigations took place, until the year 1882. In the meanwhile, in consequence of the construction of the Berlin Ring Railway, the platform of the bridge was altered in 1871, and devoted entirely to street traffic, the roadway being made 32 feet broad, with a footway on each side of 9 feet.

During this period, however, the distortion of the bridge platform had been gradually increasing, and finally, at the end of 1882, became so considerable as to demand immediate attention from the authorities. The measurements, &c., then made, showed that the hinged joint of the centre span had sunk about $4\frac{3}{8}$ inches, of the span over the Crown Prince Roadway about $2\frac{3}{4}$ inches, whilst that of the left side river span had risen $4\frac{3}{4}$ inches; the crowns of the arches over the Frederick-Carl Roadway and of the right bank stream span differed but slightly from their original level. (A small diagram shows the normal and abnormal forms of the arches.) It was also found that the left bank river-pier was about $\frac{3}{8}$-inch out of the perpendicular, and that the Crown Prince Roadway-span was increased $\frac{3}{4}$ to $1\frac{1}{4}$ inch.

During 1883 and 1884 series of levels were taken, and in the autumn of the latter year the road was closed to vehicular traffic: after this the side river-spans were relieved by timber trusses, and the question of remedial measures seriously taken into consideration.

The investigations showed that the tendency of the crown of the middle span to sink, and of the left bank river-span to rise,

having once originated (probably in the settlement of the pier foundations), was augmented by the unequal loading caused by the excess of metalling laid upon one span and the deficiency upon the other, necessitated for keeping the roadway even; thus causing an excess of horizontal thrust from the centre span, tending to tilt the piers landwards. Also that the sinking of the Crown Prince Roadway-arch was partly due to the thrust from the mass of earth forming the high-lying road, tending to push the pier riverwards. In addition to the foregoing, the fact of the centre spandril bays being without webs added to the weakness of the structure, and it may be noted that the proportion of rise to span of the arches, viz., one-twelfth, is unusually small.

The absolute amount of variation of the arch-crowns due to load-strain was difficult to ascertain, owing to the effects of temperature, but the greatest noted was $6\frac{1}{4}$ inches.

As regards the strains to which the bridge was likely to be subjected in the future, these were much greater than had originally been taken into consideration, and the traffic would tend to increase daily, especially as the new goods yard in the vicinity was about to be opened. These considerations, together with the insufficiency of the width of the river piers, and their questionable foundation, led to the determination to entirely rebuild the bridge.

A diagram shows the assumed load for each span (52 feet 6 inches) of the new structure, viz., for each footway 82 lbs. per square foot, for the roadway (32 feet broad) three wagons each of 5·9 tons, two tramcars each 8·4 tons, and a heavy wagon or steam-roller of 20 tons.

The new work was carried out in the years 1885–86, a temporary timber bridge being erected before removing the old and rebuilding the new, which comprises three arched spans, with a total opening of 162 feet 9 inches, and a breadth between parapets of 85 feet 3 inches.

The foundation of the piers is upon concrete, confined within sheet pilings.

The cost of the new bridge, including the removal of the old and erection of the temporary timber structure, was £50,000. Details of the temporary timber structure, which cost £3,200, are given, and a few diagrams illustrate the original Paper.

D. G.

Iron Tilt-bridge in Berlin. By — Pinkenburg.

(Deutsche Bauzeitung, 1887, p. 125.)

The Author describes the widening of the old Timber Bridge (Königinn Brücke) over the Luisenstadt Canal, by the erection of iron tilt-bridges on each side. The timber structure, originally erected about 1850, is formed by tilting-platforms, one on each

side of the canal, their width being 15 feet 5 inches, and span 24 feet 7 inches. The platforms of the new iron structures coincide in level with the old, and are each 13 feet 2 inches broad, so that the width is now increased to 41 feet 8 inches.

The main-bearers of each platform are balanced upon a hinged bearing, resting upon the abutment, and when tilted up to allow of the passage of canal traffic, the tails of these bearers sink to the floor of a chamber at the back of the abutment. The fixed roadway over the chamber is supported by rolled joists, resting upon the abutment and the back-wall of the chamber, and between these joists there is room for the play of the bearers. When in use for the passage of road-traffic, the tails of the bearers are secured by a stirrup and screw-gear to a transverse timber, attached to the under side of the chamber roof-joists; the platforms are so balanced as to be easily tilted by hand. Their inclination, when in service for road-traffic, is 1 in 26.

The abutments (5 feet 2 inches thick) and chamber-walls are of brickwork, in cement upon masonry foundations. Each platform is made up of five wrought-iron bearers, 3 feet apart from centre to centre, with web of $\frac{5}{16}$ inch thick, and flanges each formed of two $3\frac{1}{8}$ inches $\times$ $3\frac{1}{8}$ inches $\times$ $\frac{5}{16}$ inch angle-bars, with counter-diagonal tie-rods; they are connected transversely at four points by cross-girders, varying in depth with the main-bearers, which are $8\frac{3}{4}$ inches deep at their ends (over the canal-centre), and 2 feet $1\frac{1}{2}$ inch deep over the hinge on abutment; from here they decrease, with an irregular-shaped upper flange, to a depth of 1 foot at the tail-end. The horizontal length when in use for road-traffic, from the hinge-joint to the bearer end, is 13 feet 7 inches, and to the bearer tail 12 feet 11 inches.

The platform itself is formed by cast-steel plates resting on a transverse timber flooring, 4 inches thick, attached to the tops of the main bearers. The roof of the chamber is formed by wrought-iron joists, on which is laid transverse steel trough-decking, filled in with concrete and covered with ballast, on which are laid the paving-setts.

The work was executed in five months, and cost £1,825; the price of the cast-steel plates being 18*s.* 10*d.* per square yard.

D. G.

The Regina Margherita Bridge over the Po at Turin.

(Giornale del Genio Civile, 1887, p. 567.)

In 1876 the municipality of Turin determined upon the construction of two new bridges across the Po, one above, and one (described in the Paper) below the city. Several designs, both in masonry and iron, were considered, and it appeared that an iron bridge would be better suited to give the required headway, and would cost less money; but in spite of these advantages it was

unanimously voted that a masonry bridge should be built as being handsomer, more substantial, more monumental, and more in accordance with Italian character and traditions. The work was commenced in November 1876 and completed in March 1882, thirty-four months later than the contract time, the delay being partly accounted for by damage caused to the works by storms and floods.

The bridge consists of three main spans of 99 feet, and two flood openings of 21 feet. The foundations are of concrete on timber piles, the mass of the abutments and piers of rubble, the skew-backs, springing courses, and the whole of the face-work are of ashlar, and the arches to a large extent are built of brick with bond courses of stone.

The three main arches are elliptical, 99 feet span, and 17 feet 10 inches rise, the curves being struck with radii of 42 feet and 99 feet 9 inches.

In order to facilitate the passage of floods through the bridge (the highest on record, that of 1839, rose to within 8 feet of the crown of the arch), the faces of the arches are formed to a kind of trumpet-shape, the springings on the faces being about 8 feet higher than in the body of the arch, so that each face has a segmental curve of 148 feet radius, and 9 feet 8 inches rise, and the flood-water, instead of striking at once against a clear-cut opening, is assisted in its course by being gradually contracted to the minimum section. The cutting of the voussoirs to the required shapes was a difficult and costly process, and the stones had to be of great size, some of them weighing as much as 7 tons. They were, however, very well executed, and the joints were thin and regular.

The contract provided for the foundations to be got in by caissons, but the contractor instead put down cofferdams, using concrete instead of clay to render them watertight, and also to give greater strength to resist the force of the river in floods. The piles and other timbers in the foundations were of oak, and the load on the piles was 560 lbs. per square inch. The stone facing of the piers and abutments was granitic gneiss, and averaged about 1 foot 8 inches in depth. The weight supported by a pier at springing level, including the live load, is about 3,500 tons, which is equivalent to about $7\frac{1}{3}$ tons on the square foot. The centering for each span consisted of a timber arch, no intermediate supports between abutment and pier being used. A temporary bridge was carried by the centering at about the height of the permanent roadway, and on this ran a large travelling gantry by which the stones and other materials were lifted. The weight carried by the centering, independently of the temporary bridge, was over 2,000 tons, under which load it deflected a few centimetres only. The centering was fixed so as to allow of a settlement of 6 or 7 centimetres (2 to 3 inches) on its removal, but the actual set of the arch at the crown, when the centres were struck a month after completion, was only 5 millimetres ($\frac{1}{5}$ inch).

The following Table gives the set of a number of bridges on the centres being struck :—

Name of Bridge.	Form of Arch.	Span.	Rise.	Set.	Material.	
		Metres.	Metres.	Metres.		
Principessa Isabella at Turin . . .	Elliptical	24·00	5·30	0·005	Stone and brick	904·00
Regina Margherita at Turin . . .	,,	30·00	5·45	0·012	,,	458·00
Alma at Paris . .	,,	31·90	3·40	0·040	Stone	225·00
Severn at Gloucester	,,	45·75	10·60	0·025	,,	172·00
Diavolo over the Sill	,,	55·00	13·55	0·300	Brick	135·00
Annibale over the Volturno . . .	,,	55·00	14·02	0·295	,,	133·00
Chester over the Dee	,,	62·00	12·00	0·065	Stone	78·30
Viaduct over the Oglio	Circular	42·00	11·90	0·048	,,	73·50
Mosea over the Dora at Turin . . .	,,	45·00	5·50	0·200	,,	40·90
Over the Seine at Nantes	Elliptical	39·00	11·57	0·232	,,	14·30
,, ,, Neuilly	,,	39·00	9·75	0·295	,,	13·60
,, ,, Nogent	,,	29·24	8·77	0·372	,,	9·00

Supposing that the set (neglecting the time occupied in construction and that between completion and removal of the centres) is proportional directly to the span and inversely to the rise, dividing this ratio by the observed set, we obtain a value which will furnish a criterion of the accuracy of the work and of the quality of the cement. These values for the above bridges are given in the last column of the Table.

The calculations as to stability of the arches gave the following results. For sliding, taking the value of the coefficient of friction at 0·75, the factor of safety of the least favourable joint was $\frac{1}{1\cdot5}$. That for the pressure at the least favourable point was $\frac{1}{9\cdot2}$. The resistance to crushing of the stone employed was 21,330 lbs. per square inch, and of the bricks 2,844 lbs. The abutments are so massive that there is no danger of their being overturned.

The cost of the bridge was £34,000, or about £80 per lineal foot, or £1 8*s.* per square foot, including the abutments.

W. H. T.

Timber Rolling-Bridges in Drontheim. By W. Cauer.

(Zeitschrift für Bauwesen, 1887, p. 81.)

The road traffic between the railway station and the town of Drontheim is carried across the canal-dock by three movable bridges, crossing in each instance an opening of 32 feet 9 inches,

and varying from 31 feet 2 inches to 37 feet 5 inches in breadth, but all constructed upon the same principle, the details of which are fully given in the original.

The approaches are formed by timber-piled staging, the piles below water-level being protected from the attacks of the teredo by a shrouding of glazed earthenware pipes.

The moving portion of the bridge is formed by two platforms, comprising three lattice-girders, with cross joisting and planks; these, in opening, each slide backwards upon an arrangement of rollers, with chain gear actuated by hydraulic power. When closed across the opening, the platforms are supported by struts about 31 feet long, each pivoted on the head of a bearing-pile at the level of the canal bed; the heads of these struts carry rollers abutting against the under side of the platform, and, together with the latter, are connected with the chain gear. When the struts are drawn back into a vertical position, the platform is tilted on to a set of bearing-rollers. For closing the bridge, the chain gearing has simply to be slackened by allowing the escape of water from the hydraulic cylinder, and the platforms, owing to their inclined position, slide into their place. There are two hydraulic cylinders at each bridge, 12 feet 6 inches long and from $12\frac{3}{8}$ to $14\frac{3}{8}$ inches diameter; these are worked by the town water-supply, with a pressure of $73\frac{1}{2}$ to 103 lbs.

The working of the bridge can be governed by one man, as the hydraulic cylinders, situated one on each side of the opening, are connected under the canal bed by a pipe. Owing to the strutting, the bridges are very free from vibration when under traffic; the mean cost of each, including gearing, was £1,150.

D. G.

The Kentucky and Indiana Bridge. By Mace Moulton.

(Transactions of the American Society of Civil Engineers, Sept. 1887, p. 111.)

This bridge is a single-line railway and double roadway bridge over the Ohio river, between the cities of Louisville and New Albany. Each roadway is about 11 feet wide, and each footpath 4 feet. The total width is 47 feet. The bottom flange of the main girders is over 100 feet above low water, and the highest point of the structure is 65 feet above that. The total length is 2,453 feet. The spans are, beginning at the New Albany (Indiana) side, as follows:—

240 feet, single truss; 370 feet swing-bridge (two cantilevers of 183 feet each); 260 feet, anchorage-span; 480 feet cantilever span; 360 feet, two anchorage-spans joined (sand island immersed during floods); 480 feet, cantilever-span; 260 feet, anchorage-span.

In the three first spans the main girders are 16 feet 6 inches apart, and in the other spans they are 24 feet 6 inches apart. The length of the panels generally is 40 feet; but there are generally

no verticals except at the piers. The bottom flange is also once suspended in the middle of each panel, making the distance apart of the cross-girders 20 feet. The greatest depth of the cantilevers is 65 feet, and the smallest 28 feet. The piers are of masonry, the cantilevers of steel, and the platform-girders of iron.

The Kentucky and Indiana Bridge Company was incorporated in March 1881, Mr. John MacLeod being their Chief Engineer, and Mr. C. Shaler Smith, who made the first design, their Consulting Engineer. The foundations were begun in October 1881, and carried on till May 1882, when, owing to various circumstances, progress was stopped till October 1883. In February 1884, a rise of the river to 70 feet 6 inches above low-water caused a further stoppage, but in July 1885 all the stone piers were completed.

The superstructure was re-designed in detail by Messrs. Macdonald and Hemberle, while Mr. Mace Moulton represented the Chief Engineer.

The 240, 185, 360, and 260 feet spans were erected on staging, and the two cantilever spans without staging. This work began in May 1885. In February 1886 the junction of one of the cantilevers was effected, and in April 1886 the junction of the other. The bridge was completed on July the 15th, 1886.

A moving load is specified, consisting of two standard consolidation-engines, weighing 112,000 lbs., on four axles bearing 24,000 lbs. each, and one bearing 16,000 lbs., with their tenders each on four axles bearing 16,000 lbs. each, and a train of 2,240 lbs. per lineal foot. The length of one engine, with tender, is 65 feet. The load on the roadways and footpath is 1,200 lbs. per lineal foot.

The stresses per square inch are specified to be calculated according to the following formula:—

$$s = u\left(1 + \frac{\text{minimum stress in member}}{2 \times \text{maximum stress in member}}\right),$$

where u varies between 9,000 and 7,500 lbs. for iron, and between 14,000 and 13,000 for steel.

For members in compression, these stresses are to be further reduced according to the formula

$$s' = \frac{s}{1 + m\frac{l^2}{r^2}},$$

where m is $\frac{1}{40,000}$ for members at both ends fixed, $\frac{1}{30,000}$ at one end jointed, and $\frac{1}{20,000}$ at both ends jointed, r being the radius of gyration. The shearing strain on rivets is not to exceed 7,000 lbs. per square inch if of iron, nor 10,000 lbs. if of steel, &c., &c.

A sample steel bar, $\frac{3}{4}$ inch diameter, shall have a strength of 8,000 lbs. per square inch with 15 per cent. of elongation in 8 inches length, &c., &c.

The Appendix to the Paper contains observations of the expansion of the cantilevers at various times, tables of the

scantlings of the parts, tables of several hundred tests, and plates showing the general arrangements of the structure with a few details of importance, also strain diagrams.

The cost of the foundations, and piers was 265,438 dollars, and that of the superstructure 577,200 dollars, exclusive of engineering. There are 16,240 cubic yards of masonry at a cost of $11·67 per yard in place. The weight of the cantilever system of 1,843 feet length is 1,629,365 lbs. of iron and 2,906,192 lbs. of steel.

M. A. E.

The Ems-Jade Canal. By Major Victor Kurs.

(Deutsche Bauzeitung, 1887, p. 254–261.)

This canal, which was commenced in 1880, and completed in 1887, connects, at its western end, with the estuary of the Ems, or the Dollart, and crossing East Friesland and a strip of Oldenburg, terminates at Wilhelmshaven, on the Bay of Jade.

The principal objects of its construction were to afford a cheap means of transport of peat from the mosses intersected at its mid-length in the Aurich district to the coast districts, which are devoid of fuel, and the conveyance of fertilizing muds, manures, &c., in the reverse direction, viz., from the coast to the moorland. In this manner the mosses might be gradually drained, and the sandy heathland portion converted into good agricultural land.

The total length of the canal is 45¼ miles. A small-scale longitudinal section is given, showing the levels of high and low tide at each end, and of the water in the reaches; also the position of the locks, of which there are five, including the terminals, but excluding the Stadtgraten interchange-lock, described later on. There are basins at each end, and at two intermediate points, viz., Aurich and Abbikhave.

The level above a given datum of high water in the Dollart is 1·36 foot, and at Wilhelmshaven 4·33 feet. The ordinary level of water in the summit reach of the canal, between Wiesens and Upschört, is 16·20 feet, the highest and lowest water-levels there being 18·17 feet and 15·87 feet, or a range of 2·30 feet. This summit reach is fed from the surrounding mosses and their pools, the water being collected in channels running parallel with the canal, but at some distance from the latter, and connecting with it at a few points only, so as to reduce the intersections of the tow-path and the consequent number of bridges.

The summit-level of the canal is in from 26 to 33 feet of cutting, but the end sections, viz., Emden to Rahe, and Upschört to Wilhelmshaven, are in embankment, the canal water-surface of the latter being about 2 feet above that of the natural ground.

As the construction of the Emden end of the canal formed a "divide," as regards the drainage of the district, it was necessary

to provide a sluice outlet at Larrelt, for the land northward of the canal. This water is simply surface-water, the Tun system of sewage-removal having been adopted both at Emden and Wilhelmshaven. The cost of the alterations connected with the land drainage, and the institution of the Tun system at Emden, was £30,000, of which amount half was subscribed from the canal funds. At the Wilhelmshaven end it was inexpedient to divide the area of natural drainage, and grips have therefore been cut parallel with the canal, which are connected at intervals by transverse siphon-ducts under the latter.

Diagram cross-sections of the canal, in cutting and embankment, are given. The width of the canal surface at ordinary water-level is 51 feet 3 inches; beyond this width, there is on each side a bench of 3 feet 3 inches broad, slightly below the ordinary water-surface, and planted with rushes and reeds for breaking up wave-action. The towpath is 10 feet broad, and about 3 feet above ordinary water-level, the bottom of the canal, under the same conditions, being, at its centre, 7 feet, and at the foot of the side slopes (2 to 1), 6 feet 3 inches deep. Where the canal water is at a higher level than the natural ground, the slopes are overlaid with 2 feet of puddled clay.

The western end of the canal opens into the Emden inland water haven, from which access to the sea is gained by the old and new sea-locks; the latter has a chamber 328 feet long, a width of 49 feet 3 inches, and a depth on sill of 21 feet 4 inches. It is provided with high-crested outer gates, for protection against extraordinary spring tides in the Dollart. The marine approach channel is 59 feet broad at the bottom, with side slopes of $2\frac{1}{2}$ to 1, and a depth of 22 feet 4 inches at ordinary high water. The foundations of the lock entrances are described; that at the inland end is on piles.

Near the Emden end of the canal it is intersected, at a right angle, by a navigable water-way known as the Stadtgraben, with which it was necessary to make a connection, and as the water-surface of the canal was the higher (varying from 4 feet 7 inches to 7 feet 5 inches), a circular intercommunication lock-basin (*Kesselschleuse*), of 108 feet 3 inches diameter, was constructed at their intersection. The bottom of the basin is laid at the same level as that of the Stadtgraben; the approach from the Stadtgraben, on each side, is made by an ordinary lock-chamber, with two pairs of gates, but from the canal by a single pair of gates on either side. A diagram shows the method of working, whereby periodical through communication can be arranged for either channel, according to the preponderance of traffic, or from one channel into the other. About twelve thousand turf-boats pass up and down the Stadtgraben annually, or one hundred per day in the season. The details of the construction of the basin are described.

There are three ordinary locks at Rahe, Wiesens, and Upschört, each 108 feet 3 inches long, 21 feet 4 inches broad, with a depth of water on sill of 7 feet. The lock at the eastern end, giving access

to the new harbour basin of Wilhelmshaven (173 acres area and 28 feet deep), is 164 feet long, 24 feet 7 inches broad, and with 9 feet 10 inches depth of water on sill. There are no special passing-places provided along the course of the canal, as the largest boats navigating it are 92 feet long and 18 feet 4 inches broad, and can easily pass one another; and the turf-boats, being only 48 feet 6 inches long, can be turned anywhere, but the larger craft at either of the four basins only.

The canal is crossed by a tilt-bridge and a sliding-bridge at Emden; and elsewhere, by thirty-four swing-bridges, varying from 5 feet to 6 feet 3 inches headway.

Near Wilhelmshaven the canal crosses the Made, a stream taking most of the drainage of the district, with outfalls at the Rüsting and Marie tidal-sluices, to the north and west of the town. The level of the Made, in the highest flood, is 2 feet below that of the canal at its lowest level.

To avoid raising the level of the canal by lockage, but at the same time to permit of ample headway for the floods and ice-flow of winter, the canal is here carried in a wrought-iron trough of about 60 feet 8 inches long, 24 feet 8 inches broad, and 10 feet deep, lined with planking to protect it from injury by poling, &c. It rests upon masonry abutments, with piled foundations, and is capable of being raised and lowered by rods with screw-gear. When required to be raised, the canal-waters are shut off near each end of the trough by sluices sliding in grooved ways, and the trough then emptied. The towpath is carried independently by light iron bridges.

Diagram sections are given of the masonry abutments and of the timber templates, with oakum packing bolted to them, corresponding in profile to the exterior of the trough. The abutments are stepped to receive the trough ends, and capped with stone, to which is bolted the timber as above described. The cost of the wrought-iron trough was £1,500, and the cost of the whole works of the canal, including the Emden drainage, was £698,375.

The traffic is expected to be greatly increased when the Dortmund-Ems canal is opened, by which communication will be made with the Westphalian coal-field, from whence the large supplies necessary for the town (twenty-five thousand inhabitants) and port of Wilhelmshaven can be obtained. At present the price of peat in the terminal towns which formerly ranged from 9½*d.* to 1*s.* per cwt., is reduced to from 5½*d.* to 7*d.*

An estimate is made of the increased value of the moorland, due to its being fertilized by the sewage, &c., transported from the coast.

D. G.

The Regulation of the Elbe between Melnik and Königgrätz.

By A. Oelwein.

(Wochenschrift des österreichischen Ingenieur- und Architekten-Vereines, 1887, p. 267.)

This is part of a very large scheme promoted by the Bohemian Landtag for improving the water communications of the country, which includes not only the regulation and ultimate canalization of the Elbe between Melnik and Königgrätz, but also of the Moldau and Eger, as well as the regulation of many minor tributaries. The scheme also comprises the construction of a canal between Vienna and Budweis to connect the Danube with the Moldau river, at an estimated maximum cost of £8,000,000.

In 1884, a special commission was appointed to consider the scheme, consisting of chief engineer J. Schwarz (the Author of the project), A. Oelwein, and W. Plenkner, as technical experts, and chief councillor Piscacek, and they reported that the course of the Elbe between Melnik and Königgrätz, a distance of 196 kilometres, or 122½ miles, presented no special difficulties as regards regulation, and that for only one-fourth of that distance would it be necessary to straighten the curves, repair the banks, &c.

The average fall in this section of the Elbe is very trifling, being 0·383 per 1000, but owing to the existence of fourteen fixed weirs in the stream, this fall is not uniform, the minimum being 0·005 per 1000, and the maximum (in the 13½-mile section from Drahetitz to Celakovic) 0·39 per 1000. The general course of the river is pretty straight, and the cross-sections favourable, the widths varying from 44 to 46 metres in the first section (Königgrätz-Pardubitz) up to 82–87 metres in the last section (Lobkowitz–Melnik).

At present about 43,700 acres of fairly productive land are inundated at high-water floods, to a depth of from 4 to 20 inches, and with the existing fixed weirs in the river that level cannot be lowered. Special provision is, however, made for rafting operations.

The regulation project aimed at (*a*) The removal of serpentine curves and sharp bends, either by cutting through them, or by the construction of training-dams. (*b*) The reduction of excessive widths, and the widening of narrow parts in order to bring them to the normal section. (*c*) The construction of works to protect the banks in those reaches where the river is already regulated. (*d*) In those parts subject to floods, the construction of dams about 20 inches above highest flood-level. The new banks to have a batter of 3 feet, and to be stone-pitched down to mean water-level, and above that datum to be revetted with sods.

By cutting off the sharp curves the river's course will be

reduced from 122½ to 105 miles, and the existing average fall of 0·383 per 1000 will be increased to 0·496 per 1000. In order to minimize the evils of the fixed weirs, provision is made for the construction of under-sluices, in order to carry off the flood-waters, and to lower the flood-level from 20 to 24 inches, and where possible to replace the fixed weirs by movable ones.

Five years are allowed for the completion of the regulation works, which it is expected will prove of the greatest possible benefit to the country, and prepare the way for the canalization and navigation of the Elbe up to Königgrätz for vessels drawing 4½ feet of water. The cost of such canalization, together with towing-path, is estimated at 4½ million guldens, or £450,000, that is, about £4,300 per mile.

W. H. E.

The Canalization of the Main between Frankfort and Mainz.

(Deutsche Bauzeitung, 1887, p. 87.)

These works were necessitated by the condition into which the river had gradually fallen since the year 1840, when the amount of river-borne freight reached 492,000 tons, and the encouraging prospect led to the establishment of various steam-boat services in connection with the Rhine, &c. These expectations were disappointed by the unexpected rapid development of railways, and, in conjunction with other circumstances, brought about such a decline of trade that in 1878 the river-freight at Frankfort had fallen to 118,080 tons. The changed aspect was, however, not entirely due to railway competition, but, to a considerable extent, to the condition into which the river, as regards its navigability, had been permitted to lapse; and although works of a minor character had from time to time been carried out, they were inadequate, as is shown by the fact that in 1878 the depth of water in the Main, at its junction with the Rhine, was at one time only 18 inches.

In 1870 alternative plans were submitted to the authorities, for the construction of a navigation canal running parallel with the river, either on the left or right bank, but the idea was then abandoned for financial reasons. This was succeeded by the project forming the subject of the notice, viz., the canalization of the river itself by lockage, &c.; but after its acceptance, the execution was considerably delayed owing to difficulties in coming to an agreement with a company empowered to lay down, on the river-bed, a chain for navigation purposes, and as regards the method of constructing the locks to meet the views of the latter. This being settled, the works were commenced in May, 1883, and completed in three and a half years, at a cost of £275,000.

The length of the river affected by the works is about 25 miles, including a stretch of 4⅜ miles above the highest up-stream weir,

where in normal conditions the water-level is about that of the crest of the latter. The locks are five in number, and at the following distances from the junction of the Main with the Rhine, viz., Kostheim, $2\frac{1}{2}$ miles; Flörsheim, $6\frac{3}{4}$ miles; Okriftel, $11\frac{3}{4}$ miles; Höchst, $15\frac{1}{2}$ miles; and Frankfort, $20\frac{1}{2}$ miles.

A section accompanying the notice shows the position of the locks and weirs, with the amount of lift at each, which varies from 6 feet to 8 feet 10 inches; also the contour of the flood of 1845.

The difference in level between the normal surface of the river above the highest weir, and at its junction with the Rhine, is 35 feet 8 inches; the minimum flow of the river is 1,554 cubic feet per second; the minimum depth of water in the channel is 6 feet 7 inches, and in the lock-chambers, 8 feet 3 inches; the latter are 34 feet 6 inches wide, and 279 feet long, and the chain for navigation purposes is passed through the sill, below the gates.

The weirs are of the needle type, and there is also at each a raft-run, with shutter arrangement and a fish-pass.

When the river is in flood, vessels pass through the weirs by special openings.

As regards the construction of the weirs and other works, no unusual difficulties were met with, the foundations being favourable. The masonry was laid either in trass or Portland cement. A Table is given of the height of lift of each lock, the level of the weir crest, and of the passes in the weirs, &c. There were no works necessary in connection with the river-banks, as they had been previously regulated and were in good condition. Complaints have recently been made as to the inefficient depth of the channel at certain points; this arises from the abrasion caused by the navigation-chain in working to and fro, detaching pieces of rock, &c., from the river-bed, and at the junction of the Main and Rhine by the action of the counter-currents, but these difficulties can be readily overcome by dredging.

At the same time that the above works have been carried out by the State, the town of Frankfort has constructed a large basin, with quays, warehouses, &c., connected by sidings with the Frankfort Railway-station, and further works of a similar character are in progress on the left bank of the river.

D. G.

Regulation Works on the Rhine between Eltville and Oestrich.

By — Imroth.

(Deutsche Bauzeitung, 1887, p. 471.)

The natural water-way of the Rhine at this place is about 1,476 feet broad, and separated by an island, known as the "Westphalian Aue," into two channels, of which the main one is termed the "Grossen Geiss," and the by-channel the "Kleinen Geiss." About the year 1860 the State of Nassau commenced

works with the intention of altogether closing the by-channel, and improving the main one by widening and deepening, but the progress of the works was slow and intermittent, principally on account of the opposition to the alteration offered by those dwelling on the river bank. Parallel works were, however, laid, and a partial silting-up of the channel effected, with the result that a stagnant morass, with its accompanying unhealthy conditions, was created, adding to the dissatisfaction of those dwelling in the neighbourhood. Besides the foregoing inconvenience, it was alleged that by decreasing the area of the water-surface serious injury was being inflicted upon the adjacent vineyards, which included two of the most celebrated, viz., Marcobrunner and Johannisberg, and that, in fact, the character of the first mentioned wine had already been apparently affected. These and other considerations in 1880 led to a decision on the part of the German Government to undertake the following works.

In the lower part of the main channel the conformation of the river-bed, there composed of hard clay and gravel, was such as to interfere with the course which navigation would naturally follow, vessels having to change their direction to one at right angles to the stream, and there was also considerable expense incurred after times of flood in dredging deposits of sand. By removing this obstruction in the main channel, the navigable course would be improved, and the width could be reduced. It was therefore decided to restrict the main channel by means of parallel works to a width of 273 yards, and to open out and make navigable the by-channel to a width of 219 yards, giving a total width of water-way of 1,476 feet, as was originally the case, and removing the cause of complaint respecting the vineyards. By means of the parallel works a channel of 243 feet in breadth (at the river-bed level), and 1½ mile long, has been cut through the above-mentioned obstruction, and is now navigable for the largest Rhine craft.

This was commenced in April 1886, and completed in January 1887, and the works for re-opening the by-channel are in progress. The total cost is estimated at £600,000 (1,200,000 marks).

D. G.

Panama Canal Works.[1] By Max de Nansouty.

(Le Génie Civil, vol. xii. 1888, pp. 177 and 244, 1 plate and 13 woodcuts.)

The delays experienced, owing to the difficulties encountered in the excavation for the canal, and the high rate at which the capital has been raised, have led the company to relinquish for a time the execution of a canal, level throughout, as decided upon by the

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[1] Minutes of Proceedings Inst. C.E. vol. lxx. p. 441, vol. lxxiii. p. 421, vol. lxxviii. p. 479, and vol. lxxx. p. 398.

International Congress of 1879, and, whilst utilizing all the works hitherto executed, to complete a canal with locks in a short time. By this means, a provisional communication between the oceans will be provided at an earlier period; and the works for completing the original scheme can then be continued. The level canal, including the dredged channel in the Pacific to the island of Naos, would have a length of forty-six miles, a width of 72 feet at the bottom, and 131¼ feet at the water-level, with a depth of 28 to 29½ feet. For carrying out the works, the canal was divided into five sections, comprising the following amounts of excavation :—

		Cubic yards.
First section.	From Colon to 16⅓ miles . . .	32,700,000
Second „	„ 16⅓ miles to 27⅓ miles . .	31,400,000
Third „	„ 27⅓ „ 33⅓ „ . .	58,800,000
Fourth „	„ 33⅓ „ 35⅔ „ . .	35,300,000
Fifth „	„ 35⅔ „ Panama . .	18,300,000
	Total	176,500,000

The two first sections, on the Atlantic side, pass through the low portion of the Chagres valley; the third and fourth traverse the Cordilleras; and the fifth descends to the Pacific by the Rio Grande valley. Dredging has been mainly resorted to in the first section; and twelve dredgers of from 60 to 250 HP. are at work there, the material being either carried out to sea in hopper-barges, or deposited on the banks by long shoots. The Mindi hills, between Colon and Gatun, have been pierced; the canal has been opened up to the tenth mile, and three-fifths of the earthwork of this division have been finished. The Chagres torrent, with a discharge ranging from 350 cubic feet per second at its low stage, up to 56,500 cubic feet in flood time, is first met at Gatun, and is to be diverted. There are 1,700 men at work on this section. There are nineteen excavators of different kinds at work on the excavations of the second section, which remove about 118,000 cubic yards per month; and five dredgers of 180 HP. raise about 40,000 cubic yards per month, 2,200 men being at work on this section, in which one-eighth of the total excavation has been accomplished. The deep rocky cuttings of Emperador and Culebra are entered upon in the third section. Six excavators, sixty-six loading-cranes, forty-eight perforators for the blasting-holes, and 3,300 workmen, are employed on this section, from which about 8,000,000 cubic yards have been excavated, or about one-seventh of the whole. The large dam at Gamboa, for retaining the floods of the Chagres and Obispo, forms one of the works of this section. The fourth section, little over two miles long, includes the Culebra cutting, of which the highest point is 333½ feet above the bottom of the level canal. The works in the deep cutting have been much impeded by numerous considerable slips in the schistose rock, which filled in the trenches, displaced the roads, and overturned the excavators, and by the influx of water in the rainy season; but the excavation

is now making progress, and about 2,600,000 cubic yards have been removed, not quite one-thirteenth of the whole excavation in the section according to the original design. In this great cutting, 39 excavators, 36 locomotives, 1,277 wagons, and 1,300 men, are at work. The excavation in the fifth section is relatively easy; and as the rise of 19⅔ feet at spring-tides on the Panama side would only have created a current of 2½ knots per hour in the canal, it was proposed to dispense with a regulating lock, which may, however, become necessary again in a canal with locks. Eight excavators, 16 locomotives, 1,244 wagons, 7 dredgers, 13 hopper-barges, and 1,000 men are at work on this section, in which about one-third of the total excavation has been effected. The provisional completion of the canal, by the introduction of locks designed by Mr. Eiffel, will reduce the excavation remaining to be done from 137,300,000 cubic yards to 52,300,000 cubic yards, which, for the completion of the canal in 1890, will only necessitate the excavation of 1,570,000 cubic yards per month, exactly the amount now being accomplished in the five sections. By this means, the difficulties attending the excavation of the deep cutting, which would have required a very long time to complete, will be avoided.

Canal with Locks.—The provisional canal with locks has its upper reach so designed as to enable the works of the level canal to be continued, by making use of the powerful dredgers on the works for the excavation. The canal with locks will follow very nearly the same line as the level canal, with only slight modifications of the centre line to utilize more thoroughly the actual excavations. The canal will be at sea-level from Colon to the fourteenth mile, where the first lock, with a lift of 26¼ feet, will be placed. The second lock, with the same lift, will be placed 23⅓ miles from Colon, and the third and fourth locks, with lifts of 36$\frac{1}{11}$ feet each, at 27¼, and 28¾ miles respectively, making the summit-level 124⅔ feet above the Atlantic. The canal will descend to the Pacific by three locks of 36$\frac{1}{11}$ feet drop, situated at 35½, 35$\frac{9}{10}$, and 38⅔ miles respectively from Colon, and one lock of 26¼ feet drop at 36¾ miles, thus making up the difference in level of 134½ feet between the summit-level and low-water of spring-tides at Panama. In the event of difficulties occurring in the excavation of the Culebra cutting, the summit-level might be raised to 160¾ feet, by inserting a lock with a lift of 36$\frac{1}{11}$ feet on each slope of the Cordilleras, whereby time might be gained by a further reduction in the amount of excavation. The section adopted for the level canal will be maintained in each reach; the width of the locks will be 59 feet, and their available length 590 feet. At the Colon entrance, the canal will have a bottom width of 590 feet for 1·86 mile, and at the Panama end, 164 feet for 3¼ miles; whilst the channel in the Pacific, from the shore at Boca to Naos, will be 164 feet wide. Allowing a speed of 6¼ miles per hour in the long reaches, and 2¼ miles in the short reaches, and one hour for passing through a lock, a single ship would traverse the canal in 17 hours 28 minutes, and in a convoy, in 28 hours 25 minutes. Accordingly,

ten vessels, or 25,000 tons, could pass through the canal in twenty-four hours; so that 9,125,000 tons of traffic could be accommodated in the year; whereas the Congress estimated the traffic at first at 7,500,000 tons. The water-supply required for the above traffic would be 1,050,000 cubic yards per day, which could be obtained from the Chagres, the Obispo, and the Rio Grande. With the summit-level at $124\frac{2}{3}$ feet above the sea, it could be supplied from the reservoir created by the large dam at Gamboa; but if the summit-level was raised to $160\frac{3}{4}$ feet above the sea, pumps, not exceeding 3,600 HP., would be needed for lifting the supply the additional height. The gates for the locks are designed to be hollow iron counterbalanced caissons, suspended from a frame with rollers running on a roadway supported by a swing-bridge across the lock, and continued above the recess, at the side, into which the caisson will retreat for opening the lock. The watertight compartments at the lower part of the caisson, as well as the bottom portion, arranged to serve as a working-chamber, are to communicate with the outer air by shafts provided with air-locks, so that water, or compressed-air, can be introduced at pleasure. This arrangement will enable the counterpoise of the caisson to be readily adjusted, the different chambers to be easily reached for repairs, and the working-chamber at the base to be used for cleaning the sill from silt or *débris*. The caisson gates, in a lock of $36\frac{1}{11}$ feet lift, will be 69 feet high, 71 feet long, and $13\frac{1}{8}$ feet broad at the tail, and $32\frac{3}{4}$ feet high, 71 feet long, and $9\frac{5}{6}$ feet broad at the head of the lock. The locks, being situated in rock, will have the sides of their chambers formed of the natural rock, with a slight facing of masonry where necessary; but the side walls below the gates will be iron caissons, 18 feet broad, filled with concrete. The swing-bridges, of iron or steel, will be 18 feet wide, and 112 feet long, the swing portion being 78 feet; and the recesses for the caissons will be $98\frac{1}{2}$ feet long, and 23 feet wide at the top. The filling and emptying of the locks will be effected rapidly, and without disturbance, by two cast-iron pipes, $9\frac{1}{6}$ feet in diameter, laid in the floor of the lock, pierced with holes at the top, $6\frac{1}{2}$ feet apart, and $1\frac{1}{3}$ feet in diameter, along the whole length of the chamber, through which the water will enter or leave the lock, enabling the required volume of 52,300 cubic yards of water to be admitted or removed in fifteen minutes. The pipes, after passing under the sills at each end, will be curved, and carried vertically upwards, in the side walls, 32 feet above the floor, where cylindrical sluice-gates [1] will control the discharge. These works will absorb about 15,000 tons of wrought-iron, and 20,000 tons of cast-iron, which, according to the terms of the contract, are to be obtained from France.

L. V. H.

[1] Minutes of Proceedings Inst. C.E. vol. lxxxviii. p. 504.

A New Water-Way in Siberia. By M. W. F.

(Wochenschrift des österreichischen Ingenieur- und Architekten-Vereines, 1888, p. 34.)

This water-way will connect the rivers Obi and Yenissei, and will utilize the River Obi and its branches—Ket, Osernaja, Lomowotaja, and Jasswaja (an outlet of the "Great Lake") on one side, and on the other, the Yenissei with its tributaries, the Great and Little Kass.

A cutting, $4\frac{7}{8}$ miles long, between the Great Lake and the Little Kass will complete the connection between the two rivers.

The difference of level between the Great Lake and the River Obi is $65\frac{1}{2}$ feet, and will necessitate eight locks being built, while between the Great Lake and the Yenissei there is a fall of nearly 174 feet, which will be got over by twenty-five locks.

The Great Lake is $6\frac{1}{2}$ feet deep. The cutting, or canal, out of it is 42·6 feet wide, and 4·1 feet deep. The total amount of excavation is 719,680 cubic yards, of which 78,000 cubic yards have yet to be dug out. The works were commenced in 1883, and will be finished this year, the estimated cost being 8,000,000 roubles.

W. H. E.

New Iron Gates of the Transatlantic Lock at Havre.

By E. Widmer and H. Desprez.

(Annales des Ponts et Chaussées, 6th series, vol. xiv. 1887, p. 411, 5 plates and 13 woodcuts.)

The Transatlantic lock furnishes communication between the tidal basin and the Eure Dock of the port of Havre, and has a width of 100 feet. The granite sill has a rise of 18 feet 1 inch, and its level is 8 feet 4 inches below the zero of the marine charts (extreme low water). The two pairs of wooden gates, erected in 1861–62, 57 feet 5 inches long and 32 feet 2 inches high, with oak heel and meeting-posts and red-pine ribs, containing 17,660 cubic feet of timber in each leaf, and having cost £16,600 per pair, had become so much damaged, that new gates had become necessary as soon as possible. The use of wood was abandoned on account of the difficulty and delay in obtaining suitable sound American timber, and as the construction of the gates of iron in France would effect an economy, in such large gates, of 30 per cent., in addition to the prospect of greater durability, as indicated by the different condition of the wooden and iron gates, erected in 1866–67, at the same lock at Boulogne. The system of vertical ribs, like the needles of a weir, connecting the top and bottom panels, suggested in 1863, and satisfactorily carried out in three pair of gates of the west lock at Dunkirk more than three years ago, has been adopted

at Havre. The advantages of this system are, that the strains are much more easily calculated, and the dimensions of the parts can be therefore more precisely fixed; that the vertical ribs distribute the pressure of the water against the closed gate much better; that in this case, the height of the gate being only $34\frac{3}{4}$ feet as compared with a length of 57 feet 5 inches, a much greater stiffness is obtained with a given width than by horizontal ribs; and, lastly, that access to the inside for painting or repairs is much more easy with vertical ribs than in the spaces of, at most, $3\frac{1}{4}$ feet between horizontal ribs. The gate consists of a framework formed by an upper and lower rib connected at each extremity with two tubular girders forming the heel-post and meeting-post respectively. Nine vertical ribs divide the space between the heel-post and meeting-post into ten equal intervals, and there are two horizontal ribs between the top and bottom ones; whilst horizontal stiffeners, consisting of plates and angle-irons, strengthen the skins of iron plates which cover both faces of the gate. The space between the two lowest ribs, as far as the sixth vertical rib from the heel-post, forms a series of chambers for water; whilst the remainder of the space, up to the second intermediate horizontal rib, forms a series of air-chambers; and the portion above can be filled with the sea-water from openings in the upper face, controlled by lifting-gates, or emptied at low water, on the outer side, by pipes furnished with valves. The gate has thus a sufficient weight not to be lifted by a wave or the shock of a vessel; whilst its moment is small in relation to its axis of rotation, reducing considerably the strain on its connections, which never, under the most favourable conditions, are subjected to a strain reaching $1\frac{1}{4}$ ton per square inch for iron, and 3 tons for steel, indicating the uselessness of rollers, which generally work with difficulty in such large gates. Great care was taken to render the air-chamber perfectly tight; and a pump was provided for removing any water which might get in; and arrangements were made for filling or emptying the water compartments as required. The gates were protected by galvanizing all the ironwork; and two coats of paint having a zinc base were added. The gates were put together on the works lying flat, a long operation, owing to the difficulties in securing perfect watertightness, lasting six months in the case of the first leaf. Before the gates were erected, each portion was filled with water subjected to a pressure half as great again as it could possibly experience when in place. When ready, the gate was launched into the water, and was put in position by lifting the upper portion by means of tackle and ropes, worked by capstans, and hung from staging placed on, and overhanging the side wall. This operation was accomplished in two and a quarter hours, after experience had been gained in erecting the first leaf. Soon after the gates were in use, the bumping of the outer gates during an unusual swell caused the fracture of the cast-steel upper pin of one of the heel-posts, 1 foot in diameter, encircled by the anchor strap; and the results of some experiments consequently instituted

led to the substitution of wrought-iron for both the upper and lower pins of the heel-posts. A pair of stay gates were also added, for pressing against the outer gates to keep them steady in a swell. Each gate is provided with a retaining chain, furnished with a strong spring, fastened near the top of its upper side and to the side wall of the lock, to reduce the shocks produced in the act of closing. The cost of a pair of these gates was £12,400. The supporting gates cost £3,040, and each spring for the retaining chains £60. Full details are given at the end of the article of the calculations of the various strains on the gates employed in their design; and they show that when the gates are closed, with the greatest possible difference of level in the water on the two sides, the strain on the iron can at no part exceed $4\frac{1}{2}$ tons on the square inch.

L. V. H.

Experiments on a New Hydraulic Machine employed for Irrigation. By the Marquis de Caligny.

(Comptes rendus de l'Académie des Sciences, Paris, vol. cv. 1887, p. 226.)

The Author had constructed a pumping machine worked by a fall of water, which was described in a note to the Academy in 1882.[1] Having recognized that, in the original form, the coupling of leather between the automobile pipe and the fixed rising-main must be changed yearly, the Author has replaced this by a double-seat Cornish valve. The original apparatus would lift only from a depth of 5 or 6 yards. It was desirable to modify the apparatus to give a greater lift. The rising-pipe is now alternately closed by an air-valve, while the liquid-column rises, and open while it descends in the return oscillation. The air is compressed gradually without shock. When the compression is sufficient to lift the water to the necessary height, a valve opens from below upwards, and the water contained in a vertical pipe acquires velocity. The apparatus works automatically for an indefinite period. In the hydraulic ram compressed air is also employed, but in a different way. The water is received in a vessel, in which the air is compressed previously, and which discharges the water into the rising-main. Montgolfier tried to make the water arrive in a reservoir of air not previously compressed, but he failed in consequence of the inertia of the water in the rising-main. Here the case is different. The ascending-pipe is vertical, and the water is discharged at top into a conduit, which may be of any length, without the inertia of the water affecting the apparatus. With the present apparatus, water is lifted 9·45 metres (31 feet) with a normal fall of 2·40 metres (7·9 feet).

W. C. U.

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[1] Comptes rendus, vol. xcv. p. 1257.

The International Railway Congress at Milan, 1887.

By G. Cerbelaud.

(Mémoires de la Société des Ingénieurs Civils, November 1887, p. 379.)

The Milan meeting, held in September 1887, was the second session of the International Railway Congress; the first session was held at Brussels in 1885. To regulate the business of discussion, the subjects were formulated in a series of thirty-two questions, with respect to the way, the rolling-stock, station-work, and other subjects of administration and general management.

Question 2 relates to the use of metal sleepers, for which there does not appear to be any absolute preference to wood sleepers. Nevertheless, the quantity in use has been increased since last Congress. The cost of maintenance of metal sleepers compares advantageously with that of wood sleepers on lines of moderate traffic and speed, in the opinion of a majority, especially when the way has settled down. For main lines of heavy traffic the question remains unsolved. Respecting the system of letting the maintenance of way by contract, it is absolutely condemned, as being irreconcilable with security, but piecework is recommended wherever it can be adopted.

For the construction of metal bridges, the section is decidedly in favour of mild steel as superior to iron.

For lines of great traffic, it is recommended, with a view to minimising the cost of maintenance, that the way should be solidly constructed with heavy rails, well fastened, on good transverse timber sleepers of large bearing-surface and excellent ballast, and that the way should be thoroughly drained. The majority are of opinion that, for Vignoles rails, it is advantageous to lay metal plates between the rails and the sleepers.

The equilibration of the wheels of railway carriages has proved to give excellent results; to improve the suspension, elastic material is interposed between the body of the carriage and the under-frame. In the working of locomotives, it has been proved that the employment of balance-beams between the side-springs is favourable for economy of maintenance; and that the compound system admits of economy of fuel. For throwing on the rails, to prevent slipping, hot water is preferred to steam; the use of sand is condemned. For axle-lubrication, animal, vegetable, and mineral oils, or mixtures of them, are generally used; and they conduce to more satisfactory regularity of working than was obtained with grease-lubricants. For the bearings, special alloys, as white-metal, for instance, diminish the risks of heating on long journeys. Axle-boxes of wrought-iron, stamped out, are in course of trial, with a view to their replacing cast-iron axle-boxes. Premiums for economy of repair and working of locomotives, should be partly a fixed sum sufficient for the maintenance of the operatives, and partly a variable sum dependent on the economy effected.

For lighting trains, the old flat-wick lamps are generally condemned. Round wicks, with chimneys, are approved. Mineral oil may be advantageously substituted for vegetable oil. Rich compressed gas gives every satisfaction, but the dead weight of apparatus is augmented, and the use of oil is otherwise inconvenient. Electric light is on trial, but it is not likely to prevail until the cost of production is reduced. For heating the carriages, the system of ordinary foot-warmers is in general use, much improved by the use of acetate of soda, with which the heat lasts longer than with hot water. On the question of the conveyance of third-class passengers in express trains, it was agreed that this should be effected under given conditions. For instance, a minimum journey of 200 kilometers (124 miles) of journey should be paid for. The diminution of receipts by the transference of a number of second-class passengers into third-class carriages is compensated, on certain lines, by increase of traffic. With regard to goods-trains, classification as omnibus trains and semi-direct and direct trains, meets the requirements for the transport of fully-loaded wagons. For partially-loaded wagons, it is maintained that the minimum limit of load should be lowered: 1½ ton appears to be generally adopted. For marshalling trains at stations, opinion is unanimously in favour of gravitation, by which shunting-engines are dispensed with, and economy of time and labour is promoted. The best gradient is from 1 in 125 to 1 in 100, and the best method of skidding is the shoe-brake; but it is indispensable that the wagons should move freely, and that for this object grease-lubrication should be forbidden, being a hindrance in winter.

According to the latest experiments in the lighting of railway stations, preference may be given, according to circumstances, to petroleum, gas, lucigen (a product of oil-residues), or electricity. For large stations, electricity appears to be preferable where there is a surplus of motive power, or where the light is supplied by large companies, as in America, on favourable conditions. Good results have been given by the use of lucigen for lighting open spaces, but the general question remains open for the next Congress. The necessity for a standard unit of lighting is recognized, and the carcel-metre (the light of a carcel lamp at a distance of 1 metre) has been proposed.

D. K. C.

The Trans-Caspian Territory and Railway.[1]

By Dr. O. Heyfelder.

(Trans-Kaspien und seine Eisenbahn, Hannover, 1888.)

The Author accompanied the expedition in its advance against the Teke Turcomans, and was with the surveys and construction

[1] Minutes of Proceedings Inst. C.E. vol. lxxxvi. pp. 400–401.

corps of both sections of the Trans-Caspian railway, as chief army surgeon, the head of the expedition being General Annenkoff.

The first section of railway, viz., Michaelovsk to Kisil Arvat, was constructed in 1880–81; the second section or extension, from the latter place to Tchardshui, on the Amu Darya, or Oxus, was commenced in May 1885, and completed in December 1886. The further extension to Bokhara and Samarkand is now being constructed, and an ultimate extension to Tashkend is in contemplation.

The Author, as regards details, deals principally with the extension from Kisil Arvat.

A sketch of the history of Russian progress eastwards is given, extending over the past four hundred years, and reasons are given for the energy displayed in the rapid construction of the railway extension under consideration. It having been commenced in May 1885, Askabad was reached in the following November, and Kaschka in February 1886. "Whilst England, advancing in this direction from India, had, notwithstanding the energetic prosecution of her railways, only reached the Bolan Pass, leaving still a considerable distance between that point and Herat; Russia was at the same time in Duschak, or, in other words, had reached the foot of the mountains in which Herat lay, and distant only about 235 miles (355 versts) from this, 'The Key of India,' as it is termed by Marvin. This railway has altogether altered the whole political outlook in Central Asia, and has cut through the girdle of desert which England looked to as a protection for India."

A general description is given of the topography of the Trans-Caspian territory, viz., that area bounded on the west by the Caspian, and on the east by the Paropamisus and the Hindu Koosh. The country is, to a great extent, either steppe, affording pasturage only for a short period after the rainy season, or absolutely waterless tracts of desert, such as the Kara Kum (black sand) on the Khivan and Bokharan frontiers, and various others, covering very large areas. The oases in the vicinity of rivers, &c., are the portions cultivated, and their area might be greatly increased with a proper system of irrigation. As regards the rivers, the principal are the Amu Darya, the Murghab (white water), the Heri-rud, the Atrek, and four or five others, all of more or less importance; but it is remarkable that, with the exception of the Amu Darya and the Atrek, which fall into the Aral and Caspian Seas respectively, they all, after flowing considerable distances, finally disappear in the sands.[1] It is suggested that the waters of the Murghab, Heri-rud, and four other streams, might be united and carried in one channel, with an outfall into the Caspian, and that under Russian supervision this would prove of great benefit.

The Amu Darya has been surveyed with a view to the extension

[1] The Sir Darya, rising near Khokand, and flowing into the Aral Sea near Kazalmsk, is excluded, as outside the territory under consideration.—D. G.

of the navigable portion; at the present time vessels of the Aral flotilla are enabled to get up a considerable distance, and recently (December 1886) two steamers for the navigation of the central portion have been launched at Tchardshui. The change in the course of this river, which is supposed to have formerly flowed into the Caspian, is still progressing eastwards. Comparatively recently the boundary between the Turcoman territory and the Khanate of Bokhara coincided with the river, but at the present time the latter runs parallel with the former, but at a distance of from $6\frac{2}{3}$ to 8 miles (10 to 12 versts) to the east, and Tchardshui, once situated on the river bank, is now separated from it by a distance of 8 miles (12 versts). As regards the Zarafschan, which flows past Samarkand, and formerly emptied itself into the Amu Darya at Tchardshui, this now terminates in a small lake some distance to the east of the last-mentioned town; it is proposed to utilize its waters in irrigating an area of 1,131,260 acres where it first enters the plains. The Murghab, after leaving the mountains, is joined by the Kooshk at Ak Tepe, below Penjdeh, and, flowing past Merv, divides into a number of small branches, which are lost in the sands. Various other rivers are described, among them being the Heri-rud, which rises on the southern slope of the Sefid Koosh, and, flowing past Herat and Sarakhs, forms, for a considerable portion of its length, the boundary between Persia and Afghanistan. At Sarakhs, where it flows into the plains, its name is changed to the Tedschen, and is notable for the extreme muddiness of its bed and banks, making it a very difficult stream to ford, and rendering the surrounding district malarial and subject to a plague of small flies.

The principal oases, or districts under cultivation (from west to east), are those known as the Achal, Tedschen, Merv, Zarafschan, and Kashgar. The Zarafschan oasis is in Bokhara; it is extremely fertile, and has been described as "The Garden of Asia." It possesses, however, the drawbacks of the insalubrity of its water for drinking purposes (producing ulcers) and the advance of drifting sand from the adjacent deserts. Besides the above, there are, to the south of Merv, the oases of Jolatan and Penjdeh. The crops include wheat, maize, clover, hemp, cotton, tobacco, &c., and there are generally two harvests in each season. The towns and villages in the vicinity of the railway have been greatly improved since the construction of the latter, mud huts being replaced by substantial edifices of stone.

The most important places on the extension are Kisil Arvat, Gök Tepe, Askabad, Tedschen, Merv, and Tchardshui (thirty thousand inhabitants), and, on the length now constructing, Bokhara (seventy thousand inhabitants) and Samarkand. The mineral wealth of the country is referred to, and the people are described very favourably, both as fighters and workers.

When the first section of railway was opened, the commencement was near Michaelovsk, situated upon the Michael Bay or estuary (Michael-bucht) of the Caspian.

This creek was so shallow as to be unnavigable for the ordinary Caspian steamers drawing 9 feet, and the nearest suitable port was Kradnovosk. After consideration of various projects, it was determined to lengthen the railway 16½ miles, in extending it to the south shore of the Dardsha peninsula and there crossing a strait of 1 foot in depth, continue it on the island of Usun-Ada to a point on the south-west shore of the latter, where there was a depth of 12 feet of water. All that was necessary for making an approach-channel, was the removal by dredging of about 12,000 cubic yards of earth, which was executed in 1885–86, the station of Usun-Ada being opened in May 1886.

A map accompanies the original Paper, showing the course of the railway throughout its length, viz., from Usun-Ada to Samarkand, also a list of the stations and their distances, and the character of the district traversed.

There are forty-eight stations between Usun-Ada and Tchardshui, and sixteen are shown as intended, between the latter point and Samarkand.

The first section of railway terminated at Kisil Arvat, 160½ miles (242 versts) from Usun-Ada, and was, as before mentioned, constructed in 1880–81. The extension was commenced May 2nd, 1885, and was completed as far as Askabad on the 9th of the following November, or a length of 135¾ miles executed in six months. This portion of the line follows the former military road at the foot of the Kopet Dagh range, traversing the Achal oasis. After completing the line to Askabad, there was a week's rest before proceeding with the platelaying of the Askabad-Duschak portion. Notwithstanding that considerable difficulties were here caused by the absence of water, which had all to be conveyed in barrels on trucks, the station of Kaschka was attained about the middle of February 1886, and very soon after that date the locomotive was running as far as Duschak (402 miles from Usun-Ada). This is the most southern point of the line, and nearly midway between the Caspian and Samarkand. So far the line had followed a south-eastern course running parallel with the Persian frontier, but it here makes a bend, and leaving the latter runs north-east towards Merv and Bokhara.

From Duschak good roads lead to Sarakhs and Meshed, which have been improved by the Persian government since the opening of the railway. The road from Duschak through Sarakhs, a distance of 53 miles, after passing the latter, follows the valley of the Heri-rud direct to Herat. "As already suggested, the construction of a branch line to this town would encounter no physical difficulties; in fact, it would be the direct extension of the Merv-Duschak section of railway. On this point, the French engineer Boulangier, in his report on the Caspian railway, declares that the construction of this line, viz., Duschak to Herat, can only be a question of time."

When Duschak had been reached, the strategical object of the line was secured, so that breathing-time could be afforded after the

previous feverish exertions in urging forward the undertaking; also, the March rains, causing the overflow of the rivers Tedschen and Murghab, had damaged the embankments constructing in the Tedschen oasis and near Merv, so that it was not until April that the platelaying was recommenced. On July 2nd, the Merv station was opened, the distance from Usun-Ada being 512½ miles, and the works continued eastwards; but owing to the excessive heat from the middle of July to mid-August, delay was caused during that period, and Tchardshui (660 miles from Usun-Ada) not reached until late in the year, the station there being opened on December 1st, 1886. The two steamers already mentioned were also launched at that time for service on the Amu Darya.

The extension of the line eastwards was commenced in the spring, and the line laid, station sites, &c., fixed upon. At the crossings of the rivers Tedschen and Murghab, at present the bridges are of timber only, but it is intended to erect the permanent structures of iron as early as possible. As regards the Amu Darya, it is intended to adopt a pontoon-bridge or steam-ferry for the transit of trains; a fixed bridge being deemed unsuitable if not impracticable owing to the character of the bed and the volume of the stream, but more especially to the fact of its channel constantly tending to shift eastwards, making it probable that any bridge now constructed would be entirely deserted by the stream in, say, fifty to one hundred years hence.

Also the cost of a fixed bridge is estimated at £781,250 (5 million roubles), as against one-fifth of that sum for a pontoon-bridge which could be accommodated to the shifting river-bed.

It is not expected that any great difficulties will be experienced in the construction of the line to Samarkand; the extension from there to Tashkend, 199 miles in length, has not yet been surveyed, but it would have to cross the desert of Kizil Kena (red sand), and the Sir Darya river.

The method of construction and the character of the works are described. The bridges for drainage are at about ¼ mile apart; the earthwork is as a rule, very light. The embankments averaging about 1 foot 9 inches high, so as to keep above flood-level. The land is taken for a double-line, and a space of 12 feet broad marked out on each side. When timber was procurable, a screen has been erected on both sides of the line, as a protection against drifting snow and sand. The earthwork is formed for a single line, with a formation width of 13 feet 3 inches. The gradients generally rise from the west to the east, corresponding to the natural surface of the country passed through; between Kizil Arvat and the Amu Darya, they average 1 in 166, and from there to Samarkand, 1 in 83. Sharp curves have in no instance been found necessary, so that the line in this respect, is suitable for the heavy traffic. The rate of progress of rail-laying was very variable, the highest being three miles per day. The speed of trains varies from 10 miles per hour on the desert

portions of the line to as much as 46½ miles, the latter rate having been attained on the Kaschka-Duschak section.

One of the greatest difficulties to cope with was that of drifting sand. The method adopted successfully on the section between Merv and Tchardshui, was by laying branches of saxaul horizontally in layers between the sand forming the bank, with their ends projecting beyond the embankment slope; also sowing the slopes, &c., with native sand plants, such as tamarisk, saxaul, wild oats, &c., and planting trees in the vicinity of the stations. The water-supply was obtained by distillation of salt water, sinking artesian wells, carriage in barrels on trucks, &c.

The rolling-stock upon the line between Usun-Ada and the Amu Darya comprises 84 locomotives, 4 steam-cars (Dampfwagen), 922 covered wagons, 489 open wagons, and 50 ballast-wagons; also 188 tank-wagons for the conveyance of water or naphtha.

For the section under construction, namely Amu Darya—Samarkand, there are 26 locomotives, 320 covered wagons, and 80 open wagons. The fuel for the locomotives is naphtha refuse from Baku and Naphtha Dagh, which is stored at the main stations; at Askabad there is, for this purpose, a reservoir sufficient for 315 tons.

The Paper concludes with a review of the climate and its influence on health, and a biography of General Annenkoff.

In addition to the map showing the course of the line and the stations, there are also several illustrations from photographs.

D. G.

The Uleaborg Railway in Finland. By M. Strukel.

(Deutsche Bauzeitung, 1887, pp. 109, 129, 133.)

This railway, commenced in 1884, and opened for traffic in October 1886, forms part of a system intended to open up the interior of the country, by lines running in a northerly direction, starting at various points from a base formed by the railway connecting St. Petersburg and Abo.

The line commences at Oestermyra, and runs northwards till about 6 miles east of the coast town of Nykarleby, where it bends to the north-east, and passing to the east of Jakobstad runs near the coast to Gamla Karleby; from the latter place it again bends inland, and keeps at a distance of from 18 to 25 miles from the coast until within about 12 miles from its termination at Uleaborg. The general course of the line was kept inland with a view to reducing as much as possible the cost of crossing the numerous rivers, and to better develop the inland districts. Its length from Oestermyra to Uleaborg is 207¼ miles, and in addition there is an extension 2⅓ miles long from the latter place to the Port at Toppila, also a branch of 3 miles from Gamla Karleby to its port at Yxpila, and a branch to Jakobstad, the latter not yet completed. Both

the gradients and curves of the line are good; of the whole length 20·9 per cent. is horizontal, 64·4 per cent. on gradients of less than 1 in 100, the remainder being of the maximum gradient, viz., 1 in 100, and as regards direction 81·7 per cent. is on the straight, the least radius of curvature being 26½ chains. The level of rails above the sea, at Oestermyra is 143 feet, at Gamla Karleby 14 feet, at the summit, half way between the latter place and Uleaborg, 382 feet, and at Toppila 9·4 feet. The line is single, and the gauge that of the Russian railways generally, viz., 5 feet.

The rails are of steel, weighing 45 lbs. per lineal yard, and for this line are of English make, as also are those for the Savolaks Railway now constructing; those obtained from Germany for the Wasa line gave much dissatisfaction owing to the number of breakages, to which a temperature of occasionally −40° Centigrade conduces. The specification for rails is given as regards composition and tests.

The bridges are very numerous, owing to the great number of streams flowing into the Gulf of Bothnia, and include one hundred and twenty-one girder structures, varying from 6 feet 6 inches to 328 feet span; the largest of these, viz., 328 feet span, is across the Uleaelf, near Uleaborg, and carries, in addition to the railway track, a footway of 5 feet broad on each side, thereby increasing the breadth of the bridge and making it more proportional to the depth of the girders, which are 20 feet 9 inches and 45 feet 9 inches at the ends and centres respectively. The total weight of iron-work for this structure amounted to 2,008 tons, the price paid being £13 10*s.* per ton for 272 tons, and £14 10*s.* per ton for the remainder (delivered in Finnish harbour, but exclusive of duty, land transport, and erection). The specified resistances to tensile strain are given, and the amount of elongation. The abutments and piers are of granite.

A description of the stations and guard-houses is given, and of the rolling-stock, and the Paper is illustrated by a plan of the line, sections of the rail, and formation, also types of girders and plan of stations.

The cost of the Uleaborg Railway was £800,000, or about £3,748 19*s.* per mile.

D. G.

The Höllenthal Railway.

(Deutsche Bauzeitung, 1887, p. 285.)

The idea of constructing a line to connect the town of Freiburg (Baden) with Donaueschingen, thereby putting the former in direct communication with the districts adjacent to the Lake of Constance (Boden See) has formed the subject of various projects for many years past, and an account is given of the financial and other difficulties dealt with.

The railway recently opened is single line, about 21¾ miles in length, of 4 feet 8½ inches gauge, and extends from its junction with the main line at Freiburg eastwards to Neustadt, or a point more than half-way to Donaueschingen. It was commenced in 1884 and finished in June 1887. The level of the rails, above the sea, at Freiburg is 881·07 feet; the line rises thence for a distance of 15½ miles to its summit-level, viz., 2,902·80 feet, and falls again to its termination at Neustadt, where the level is 2,640 feet. The comparatively level portion is worked in the ordinary manner by adhesion, but the steep inclines are worked with the aid of a rack-rail on the Riggenbach system. The steepest gradient on the adhesion portion (11½ and 5¾ miles at each end) is 1 in 40, and on the rack-rail portion (4½ miles) it varies from 1 in 18 to 1 in 26. Of the adhesion portion 15·4 per cent. is horizontal, and of the rack-rail portion 13·5 per cent. (at the stations). Of the first-mentioned 54 per cent. is on the straight, and of the latter 44 per cent., the least radius of curves being 12 chains, of which, however, there are fifty-six recurrences. There are ten stations varying from 1 mile to 3½ miles apart, and seven tunnels. The cost of tunnelling averaged £44 3*s.* 10*d.* per lineal yard, and of each entrance £205; the character of the strata was unfavourable. The most important bridge is that across the Ravenna gorge, with four openings, each of 115 feet span. The rails are of steel 5 inches deep, weighing 73 lbs. per yard, and carried on either wrought- or cast-iron sleepers. The weight of the permanent way of the adhesion portion of the line is 247 lbs. per lineal yard, and on the rack-rail portion (exclusive of weight of rack-rail) 257 lbs. per lineal yard. The rack-rail is in lengths of 9 feet 10 inches divided into thirty teeth, and weighs 203 lbs. per lineal yard. The locomotives have four cylinders, two for actuating the ordinary adhesion driving-wheels, and two for the toothed wheels, the former independent of the latter motor. The brake arrangements are also referred to.

D. G.

Rack Railway on Mount Pilatus, Switzerland. By A. Frank.

(Zeitschrift des Vereines deutscher Ingenieure, 1887, p. 1117.)

Amongst recent rack-lines, the railway up Mount Pilatus, on the Lake of Lucerne, is especially noticeable on account of the difficulties of the route and many novel points in constructive detail. The line commences at Alpnach, and has a total length of 2 miles 61 chains, of which 1 mile 30 chains is straight, and 1 mile 31 chains on curves of 4 to 5 chains radius. In this length the line rises 5,363 feet, the mean rise being 1 in 2·8, and the steepest 1 in 2. The summit-level is 6,812 feet above the sea-level.

The greatest care has necessarily been bestowed upon the solid

and secure formation of the permanent way. The sleepers, which are of iron, are securely bolted to two parallel longitudinal walls with granite copings. The central rack-rail is of steel, with flat top and teeth on both sides, gearing into the horizontal pinion driving-wheels. The rail is in lengths of 9 feet 10 inches, with teeth $1\frac{5}{8}$ inch wide and $3\frac{3}{8}$ inches pitch, and is carried on a saddle-iron bolted on inverted channel-iron, which in turn is riveted by angle-iron joints on to the sleeper; the total bearing width on the sleeper, between the rivets, being 1 foot $\frac{1}{2}$ inch. The sleepers are of rolled channel-iron, $5\frac{1}{2}$ inches wide and 3 feet $11\frac{1}{4}$ inches long. The ordinary rails are $4\frac{3}{4}$ inches high and in lengths of 19 feet 8 inches, and the gauge is 2 feet $7\frac{1}{2}$ inches.

The combined locomotive and car was built at the Swiss Locomotive Works at Winterthur, the arrangement being designed to minimise the weight, which is in this case only 10 tons 6 cwt. The car portion consists of four compartments, and provides accommodation for thirty-two passengers. The width over framing is 6 feet 3 inches. The underframing consists of two wrought-iron girders 12 inches deep, with strong transverse bracing, and the tire-wheels are 1 foot $3\frac{3}{4}$ inches in diameter. The locomotive has a tubular boiler placed transversely to the axis of the line, and constructed for a normal pressure of 176 lbs. per square inch. It has a length of 6 feet 8 inches, and a heating-surface of 215 square feet. The two cylinders, $8\frac{5}{8}$ inches in diameter and $11\frac{3}{4}$ inches stroke, are placed outside the underframing, 3 feet $4\frac{3}{4}$ inches apart centre to centre. The connecting-rods work a horizontal shaft on which a small pinion-wheel is cottered; and this, by a second wheel with bevel-gearing, sets in motion the vertical shaft carrying the toothed driving-wheels, which have a pitch-line diameter of 1 foot $4\frac{1}{8}$ inches. There are fifteen teeth in each driving-wheel.

The brakes are naturally of the highest importance. The two pairs of pinion-wheels are generally controlled by two hand-brakes, which are sufficiently powerful to regulate the speed on the down journey as well as to stop the train. At the same time there is an atmospheric brake, similar to that in use on the Rigi line, for use on the down journeys. A reserve automatic brake is also provided, which comes into action whenever the downward speed exceeds 4·26 feet per second (about 3 miles per hour), and can also be worked by hand.

On account of the violent storms occasionally occurring on Mount Pilatus, it was considered advisable to fix on the framing of the car two side-clamps, which underhang the rail-heads, and so prevent the wheels leaving the rails.

The line was built in sections, each length being used for the transport of materials for the next length. This arrangement greatly facilitated the construction, and tested practically its working capacity.

P. W. B.

The Incline Railway at Look-Out Mountain. By W. H. Adams.

(Transactions of the American Institute of Mining Engineers, July 1887.)

This line connects the valley of the Tennessee river with the high cliff known as the Look-Out Mountain, near Chattanooga, which is one of the principal natural attractions of the Southern States both as regards scenery and historical associations. It is 4,360 feet long, with a difference of level at the ends of 1,170 feet, corresponding to a gradient of 1 in $3\frac{3}{4}$. About 1,400 feet near the top are in curves of 1,012, 1,146, and 1,323 feet radii, the remainder being straight. The line is single, with a passing place 200 feet long near the centre; but three rails are used throughout, in order to avoid the use of movable parts, so that there may be no risk of accidents from their failure in work. The gauge of the line is 3 feet 3 inches; the rails of steel, weighing 25 lbs. to the yard, are laid upon cedar sleepers 9 feet long, and about 2 feet apart. Instead of spikes, heavy lag-screws 5 inches long are used, their heads being reinforced by wrought-iron washers, 2 inches by 3 inches, which grip the base of the rail. The traction is effected by a wire cable moved by steam-power from the lower end of the line. The cable consists of two sections; the upper one, 4,360 feet long, passes over a sheave 8 feet in diameter at the summit, and its ends are attached to the two cars, giving the well-known balanced hoist where the power is applied at the top. In this case, however, as the power is applied below, the ends are spliced below the cars to those of a second section of cable, giving a continuous driving-rope. The upper or working-cable, $1\frac{1}{4}$ inch in diameter, is made up of six strands of nineteen wires each. The ultimate strength is 50 tons, while the working-load does not exceed 5 tons. The driving-rope contains the same number of wires, but is only 1 inch in diameter. The reversing sheave at the summit is held in place by a wooden frame anchored to masonry piers bolted to the rock, while the lower rope passes over grooved driving and tightening pulleys, the latter being mounted on a sliding frame with an attached counterpoise, serving to keep the cable uniformly level and to allow for changes of temperature or sudden strain. The engines, built by Wheeland, of Chattanooga, have two cylinders 12 inches by 18 inches, with a 20-inch steel pinion on the driving-shaft, which gears into two 80-inch spur wheels connected with the grooved driving-sheaves. The engines are controlled by a system of levers from the tower of the engine-house, which commands a nearly continuous view of the line. The working steam-pressure is 75 lbs., from 1,600 to 2,000 lbs. of coal being consumed per day for eighteen to twenty-four trips, or about 90 lbs. of coal per round trip. The engines make about 160 revolutions per minute, with a cut-off at about two-thirds of the stroke, the expenditure of power being remarkably small when account is taken of the resistance of the one

hundred and fifty guide-pulleys, the reversing-sheaves, stiffness of the ropes, &c.

The signalling arrangements are so contrived that the conducting-wires communicate directly with the engine-house whether the cars are standing or running. For the purpose an eight-cell Leclanché battery, with an electric gong, is placed in the engine-room, one pole being connected with the bearing of the main sheave, and therefore with the cable to form the ground circuit, while the other is in connection through the gong with an insulated telegraph placed between the rails and 6 inches above them. To complete the circuit it is only necessary to connect the wire with the cable, which can be done at any point by pressing upon a spring which is secured at the other end to the cable at its point of attachment to the car. To prevent accidents from mistaken signals, it is understood that any signal whatever made while the engines are in motion means stop, while for starting a certain definite combination is required, which of course can be deliberately made. If the cable were to break at any point the connection with the engine-house will be maintained one way or the other, and if the car should leave the rails the spring, by coming in contact with the insulated wire, would give a stop-signal immediately.

The cars have inclined floors parallel to the slope of the line, about 20 feet long and 6 feet 4 inches broad, with six rows of transverse benches arranged in steps. There is a light roof overhead supported on four corner pillars. The brake is of a special construction, and requires to be kept off by hand when the car is running. When the near wheel is released the brakes are forced under the front of the wheels, lifting from the rails, and converting the car into a sledge with the brakes for runners. The bottoms of the brakes are now made of wrought-iron, with twenty-four short steel pins projecting, which are sharpened like an engineer's tool; but it is proposed to try a shoe with a V-shaped groove to take the head of the rail, in order to increase the friction by the wedging action of the groove upon the rail under the weight of the car and its load.

H. B.

The Reconstruction of the Town of Szegedin. By J. Stübben.

(Deutsche Bauzeitung, 1887, p. 3, *et seq.*)

The destruction by flood of the greater part of this town, one of the most important in Southern Hungary, occurred in March 1879. On the 6th of that month the Percsovaer dam, situated about 13½ miles (22 kilometers) above Szegedin, was carried away, followed on the 22nd by the breaching of the Alföld Railway embankment, close to the town. The water rose to the level of 26·45 feet above datum, or a depth of 13 to 16 feet over the greater part of the town area. The consequent destruction of life and

property was very considerable; of six thousand houses, only two hundred and sixty-nine, situated in a somewhat higher-lying portion of the town, were left habitable, and of seventy thousand people, more than two-thirds were left houseless.

While the question of the regulation of the river Theiss, and the reconstruction of the town, was under consideration by an International Commission, the inundated town, after making good the railway embankment, was cleared of water by means of one hundred and sixteen centrifugal pumps, driven by forty-four portable engines, and occupied from June 15th to August 30th, at a cost of over £25,000, the repairs of the railway embankment amounting to twice that sum.

The Commission recommended the construction of a flood-way 492 feet in breadth in the Austrian State Railway embankment, the regulation of the river, where flowing past the town, to a uniform channel of 410 yards broad (between the dams), the removal of the Bridge-of-boats jetty, the raising of the town dam to a height of 31·17 feet,[1] and of that above the town to 27·88 feet, so that, should similar floods again occur, the last-mentioned would be over-topped first; and lastly, the raising of the town roadways, and the construction of a ring-dam encircling a certain town area. Besides the foregoing, there were to be carried out a great number of works for the regulation of the river below the town.

The facts that the carrying out of the regulation works, which included one hundred and thirteen diversions at the worst bends, had, previous to the catastrophe, been mostly confined to the upper part of the river, and that its tributary streams, Hernad, Bodrog, &c., have considerable falls; whereas, on the other hand, the river below Szegedin has a gradient of only 1 in 55,000, were naturally eminently conducive to the disastrous results which ensued.

The works, as recommended by the Commission, were carried out, subject to modifications, one being the carrying up the dam, leading from the upper end of the town, to a height of 32·81 feet, instead of 27·88 feet, this change being due to the flood of 1881 having attained a level of 1·30 foot more than that of the year of the catastrophe, 1879. It is constructed with a crest 19 feet 8 inches broad, and a bankette at about mid-height on its inner or landward slope of 16 feet 5 inches broad; the inner slope is 2 to 1, and outer, or river slope, 4 to 1. The new dams of this section follow the course of the river on both banks upwards, to the crossing of the latter by the Alföld Railway at Algyo (about 6¼ miles above Szegedin). From this last point a new dam, of similar section, runs westwards to Sövenyhaza, where it meets the higher-lying land; it is faced with stone pitching, and forms the outer line of flood-defence for Szegedin. On the left bank,

[1] "Above datum" is to be understood in these and other like dimensions.—D. G.

which is similarly protected, there is, above the confluence of the River Maros, a pumping-station for draining the Polder.

Below Szegedin there were constructed new dams of the same section, and carried up to the same level as the foregoing. The encircling dam recommended by the Commission was constructed to include a much larger area than that first suggested. It is $10\frac{1}{2}$ miles in length, of which $4\frac{1}{3}$ miles are formed by the embankments of the Alföld Railway and the Austrian State Railway, the new dam being of the same section and level as the above, and serves as a second line of flood-defence.

Where passing through the town, the channel, formerly 219 yards broad, has, by the lowering of a spit of land of 191 yards in breadth, &c., been regulated so as to form between the boundary dams a low-water channel, on the Szegedin side, of 164 yards, and a breadth of 219 to 274 yards on the New Szegedin or Elizabethstadt side, covered during floods. The level of the dam upon the Szegedin side is + 29·53 feet, of that on the left bank + 32·81 feet; the natural surface of the ground averages + 14·75 feet, the mean water-level + 9·84 feet, and the river bed from − 20 feet to − 43 feet.

For preserving the channel and enabling vessels to come alongside the wharves, dredging is necessary, owing to the large quantities of mud brought down by the Maros, which flows into the Theiss immediately above the town.

In the actual town area there is an inner and outer "Ringstrasse," their levels being respectively + 26·97 feet and 24·61 feet, and their breadths 98 feet 6 inches and 124 feet 8 inches. These form additional flood-barriers, and, as they are for security not permitted to be pierced either by pipes or sewers, a distinct system of drainage is required for the different areas separated by these dams. A diagram of these systems, and the position of the three pumping-stations (one of which is at work for three months in the year, another six weeks, and the third only occasionally) accompanies the Paper; also a plan of the town, showing the direction of the main streets which radiate from the inner town, where also is the highest-lying natural ground.

The drains are, for the purpose of obtaining sufficient fall, in some cases as much as 6 feet 6 inches above the land surface.

There are many open spaces, including a park of 42 acres on the Elizabethstadt side, and the principal square, viz., the Szechényi Plaz, 984 feet long and 558 feet broad, on the Szegedin side. Although it is intended ultimately to bring the streets up to the level of the Ringstrasses, at present only the main thoroughfares have been made up; the rest are laid out on the undrained land, and, where built on, the houses are so designed that the present entrance floors shall hereafter serve as cellars.

Cross-sections are given of the principal roadways; these are paved with stone cubes in the centre, but their condition is very unsatisfactory. A supply of good drinking-water is much needed, and the subject has been for some time under consideration. The

question, although of vital importance, in view of previous visitations of cholera, is one difficult of solution, as the supply must be obtained from the muddy waters of the Theiss, and will require filtration processes of an expensive character to render it fit for the purpose.

A general description is given of the town and its inhabitants, now numbering about seventy thousand, the value of land, &c.

As regards railway accommodation, the station of the Austro-Hungarian Railway is situated on the river bank, at the southern end of the town, and that of the Alföld Fiumine Railway to the west of the town. The former railway crosses the river by a wrought-iron framed girder bridge of six spans, with cast-iron cylinder-piers, sunk by pneumatic process.

The old Bridge-of-boats has been replaced by a wrought-iron construction, of four arches of 393 feet 9 inches, 311 feet 8 inches, 279 feet, and 262 feet 6 inches span, at a cost of £150,000.

D. G.

On the Principles involved in the Production of Pure Water by means of Filtration.[1]

By C. Piefke, Resident Engineer of the Berlin Waterworks.

The Author states, in his introduction, that the variations in the quality of the water supplied to Berlin necessitated a thorough investigation; and that for this purpose a special laboratory was erected which gave the means of searching and systematic inquiry. He points out that sand-filtration must be investigated under a three-fold aspect, depending upon the mechanical, the physiological, and the chemical effects produced.

With respect to the mechanical action of filters, it is pointed out that the grains of sand used cannot be smaller than $\frac{1}{2}$ millimetre in diameter, and that they consequently form between them zigzag channels, the water flowing through, which may be regarded as a torrent compared with the dimensions of the particles which cause impurity in water. Bacterioscopic investigations have shown that the germs of certain organisms hardly attain a diameter of $\frac{1}{1000}$ of a millimetre, and that the particles of argillaceous matter, which cause opalescence, and which precipitate very slowly, do not reach one-tenth of those dimensions, so that the chances of all these particles adhering to the surfaces of the sand-grains become remote, especially in thin sand-layers and with rapid filtration. The Author attempted to determine the number

[1] "Die Principien der Reinwasser-Gewinnung vermittelst Filtration. Bericht an die Direction der städtischen Wasserwerke zu Berlin. Von C. Piefke." Berlin, 1887. A copy is in the Library of the Inst. C.E.

and the diameter of the particles causing opalescence by direct experiment, and arrived at the conclusion that three hundred million particles float in a single cubic centimetre, and that such water would not filter clear, either very slowly through sand or through Swedish filter paper. He discusses the effect of the surface deposit on the sand, and concludes that it is not, in all cases, competent to arrest extremely minute impurities, though old filter-beds prove more efficient than those freshly filled.

With respect to the physiological effect of filtration, the Author points out how insignificant is the number of organisms contained in even very impure water compared with the number of inorganic particles, and yet it is proved that perfectly clean and sterilized sand is incompetent to arrest the passage of microscopic creatures or their germs, indeed it is found that old filters are, in this case, more efficient also; and he asserts that under the microscope the sand-grains appear covered by a pellicle which is dissipated by heat, and which consists of organic matter and a little oxide of iron.

An examination of old filter-beds revealed the amazing numbers of germs adhering to the surfaces of the sand-grains; the numbers are found to decrease rapidly in proportion to the distance from the surface, a fact which is illustrated by tables of experiments and by means of curves.

Experiments instituted for the purpose of ascertaining the effect produced by filtering the Spree water through sterilized sand are described, and it is shown that the surface layer of impurities acts as a nursery for microscopic organisms to such an extent that the water after filtration was richer in life than before. The rate of filtration and the effect of the gradual thinning of the sand-layer by repeated cleaning is discussed, and much useful practical information is given on the best methods of working filters.

The chemical aspects of filtration are next examined, and the Author points out, in the first instance, the immense advantage of natural over artificial filtration on account of the extreme slowness of the former, which he calculates for the neighbourhood of Berlin to be $\frac{1}{2,510}$ less than the rate of ordinary filter-beds, hence but little chemical improvement in water from artificial filtration can be looked for.

The Author next proceeds to consider the chemical means of purifying water. He points out that it is undesirable to furnish a supply which will require to be dealt with in domestic filters because their action, even if effective, reaches only the water actually used for drinking purposes, and he draws attention to the fact that most filters, especially those depending on the action of charcoal, so far from improving the water passed through them in a hygienic point of view, actually render it less fit for use.

Many substances, such as lime, alum, salts of iron, have the property of causing rapid precipitation of solid impurities, but some of these reagents contaminate the water to an appreciable degree,

and are therefore objectionable. The use of sulphate of alumina is described, and instances given from which the cost of the application is calculated and found to be very serious, amounting to as much as three times the cost of simple filtration.

The latter part of the pamphlet is devoted to an examination of the purification of water by means of metallic iron. The theory of the action of Bischof's spongy iron is discussed, mainly in the light of the great experiment made by Messrs. Easton & Anderson at the Antwerp Waterworks; the partial failure of that experiment is described, and the method, afterwards adopted with complete success, of causing the iron to mix with the water in revolving purifiers is discussed at considerable length, and the value of the subsequent sand-filtration is examined. The Author proceeds to describe the experiments made at the Berlin Waterworks with the Anderson revolving purifier, which was shown at work at the Health Exhibition in London. Tables of the bacteriological and chemical observations are given, the importance of energetic aeration of the water after or during contact with the iron is pointed out; and the Author describes a modification of the Anderson system whereby this object is more fully attained with most satisfactory results, at any rate with the peculiar waters of the Spree.

W. A.

On the Separation of Iron-Compounds from Drinking-Water, and the Removal from it of Sulphuretted Hydrogen.

By F. Kaeber of Charlottenburg.

(Deutsche Vierteljahrsschrift für öffentliche Gesundheitspflege, 1888, p. 117.)

Successful attempts have been for some time past in progress to free the water of Charlottenburg from iron and sulphuretted hydrogen, and the Author considers that an account of the simple process adopted there may interest others where similar conditions have been found to prevail. The Charlottenburg Water Company took over the bankrupt undertaking of the Westend Company in 1878. The latter concern, which had failed in 1873, had lost all sale for the water, owing to its uselessness for domestic purposes. An account is given of the early history of the Westend company, which derived its supply from numerous tube-wells, varying from 90 feet to 125 feet in depth, sunk through a stratum of clay from 3 feet to 16 feet in thickness, situated from 50 feet to 65 feet below the soil, into a deep bed of water-bearing gravel. These borings were connected together by underground siphon-conduits, which brought the water from sixteen of them into one common sump, from which the water was pumped into the rising-main, and so into the compensation high-pressure reservoir on the Spandau Road. The general arrangement of the works is explained by reference to a plan. As the pipe-system for the dis-

tribution was gradually extended, in consequence of the small quantity of water used in certain streets, the introduction of dead-ends, and the possibility only in certain cases of a blow-through, the water stagnated, and as, in common with all the local surface-waters, it was rich in iron, a partial decomposition of the carbonate of the protoxide of iron took place, causing turbidity due to the formation of the hydrated oxide of iron. Moreover, when the supply was first drawn from the mains in the morning, there was a marked smell of sulphuretted hydrogen, which occasioned frequent complaints on the part of the consumers. The fact that, on the admixture of the water with air, the smell of this gas disappears, and that a separation of the iron compounds takes place, led the company, in the autumn of 1886, to attempt an artificial aeration of the water. This was at first carried out as follows:—The water was raised from the sump by a centrifugal-pump into a ring-shaped receiver, placed above it, out of which it escaped in a species of waterfall, mixing freely in its descent with atmospheric air, admitted from the outside for this purpose. An important improvement in the quality of the water was effected by this means, but the water was thrown into the vessel with such force as to splash over and permanently wet the entire superstructure. In order to avoid this, the ring-shaped vessel was raised 4 feet, and was perforated with 1,600 holes, each 0·11 inch in diameter, through which the water escaped in the form of rain into the reservoir. Provision was made for the free passage of air through and through this artificial rainfall by means of side-openings, pierced through the masonry of the structure. After these alterations had been carried out, the iron in the water, which at first amounted to 1·657 part per 100,000, sank to 0·36 part, and the obnoxious smell was entirely removed. These arrangements are shown in a diagram. These very favourable results have induced the company to extend their operations, for the supply of the district outside Charlottenburg, situated between Berlin and Potsdam, and a lofty water-tower has been erected on the Fichtenberg, at Steglitz,[1] for this purpose, having at the top a reservoir with a capacity of 440,200 gallons.

G. R. R.

The Gas- and Water-Supply of Berlin. By O. Leonhardt.

(Gesundheits-Ingenieur, 1888, p. 86.)

The gasworks of Berlin were conducted at a loss until July 1st, 1850, which loss had, however, been recovered by the year 1853, and up to 1867 there was a total balance of profit of 9,309,000 marks (£465,450), which had been applied towards the extension of the

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[1] Minutes of Proceedings Inst. C.E. vol. xc. p. 513.

works. The original price of the gas was very high, but previous to 1878 it had been reduced to 16 pfennige per cubic metre (about 4*s.* 6*d.* per 1000 cubic feet), at which figure it still remained for all gas used for illuminating purposes. Since last November, however, gas used for any other purpose is supplied at a discount of 20 per cent. The consumption was at first small, but rapidly increased, and is still growing, as will be seen by the following figures:—

Financial Year.	Gas used in Cubic Metres.	Percentage of Increase.	Date.	Maximum quantity used in one Day in Cubic Metres.	Percentage of Increase.
1 April, 1882–83	68,442,000	3·7	16 Dec. 1882	358,500	2·4
1 April, 1883–84	70,529,000	3·1	21 Dec. 1883	375,500	4·7
1 April, 1884–85	74,338,000	5·4	19 Dec. 1884	393,400	4·8
1 April, 1885–86	77,826,000	4·7	23 Dec. 1885	408,400	3·8
1 April, 1886–87	81,274,000	4·4	18 Dec. 1886	426,400	4·4
Average in the five years		4·3	Average for the last five years . .		4·0

These figures relate to four works, in different parts of the town, but do not include the returns from the works of the Imperial Continental Gas Association, from which no official statistics are communicated. The probable annual receipts of this latter company are stated at upwards of 2,062,000 marks (£103,100). The following are the approximate estimates of the maximum amounts of gas needed on any one day for the next three years—479,000 cubic metres in 1888, 508,000 in 1889, and 538,000 in 1890.

The water-supply of Berlin was, up to 1874, in the hands of an English company—"The City of Berlin Waterworks." This company, founded in 1856, had, for the first ten years of its existence, a possible daily yield of 40,000 cubic metres. By means of an extension, completed in 1868, this volume was doubled. After the works had been purchased by the municipality in 1874, it soon became necessary to provide for an increased yield, and, owing to the polluted character of the Spree water, it was decided to construct entirely new works on Lake Tegel, which were planned so as to be executed half at a time—the first half to be completed in 1877, the second in 1886. The difficulties caused by the appearance of the crenothrix are well known, and led to the ultimate use of well-water. Berlin is now partly supplied with Spree water, partly with water from Lake Tegel, and a system of sand-filtration is employed for each supply. On the 31st of March, 1886, 18,659 blocks were supplied with water, and on the 31st of March, 1887, water was laid on to 19,193 blocks. Each average block

contains 60·61 inhabitants, so that a total population of 1,156,802 persons were provided with water in the years 1886–87. During the financial year, 29,967,790 cubic metres of water were consumed, an average of 71·55 litres per head per diem. The maximum volume was 97·29 litres on the 4th of September, 1886, and the minimum volume 51·82 litres on the 26th of December. The use of water for manufacturing purposes is very considerable, and in 471 establishments, supplied at a cheaper rate, there is a daily consumption of 35,000 cubic metres, or about 30 per cent. of the total supply. The two existing waterworks are capable of furnishing a total daily supply of 172,000 cubic metres, or 2 cubic metres per second. But as, owing to the rapid increase of the town, this yield will shortly be insufficient, a third waterworks is to be constructed on the banks of Lake Müggel, about 20 kilometres distant from Berlin. These works will be equal to the joint capacity of the two existing waterworks, and will entail, together with the necessary mains, an estimated expenditure of 20,000,000 marks, or £1,000,000 sterling. The price of the Berlin water is 20 pfennige per cubic metre = 10·9*d.* per 1000 gallons.

G. R. R.

The Water-Supply of Stralsund.

(Deutsche Vierteljahrsschrift für öffentliche Gesundheitspflege, 1888, p. 137.)

The municipal authorities of Stralsund controvert the statements of Dr. Ziegeler[1] respecting the insanitary condition of their town, and refer more especially to the projects he favours for the improvement of the water-supply, namely, the substitution of the Frankenteich for the Knieperteich, and the adoption of the water from Garbodehagen. With respect to the former suggestion, they assert that the area of the Frankenteich supply is 300 per cent. smaller than that of the Knieperteich, and that experts are of the opinion that, in the absence of rainfall, the lake would be pumped dry in three weeks. Concerning the latter supply, which would be so small as only to serve a very limited district, experiments are in hand to test the character of the water. In the meanwhile the scheme proposed by Mr. A. Thiem, of Leipzig, is still under consideration. A detailed account of this scheme, by the Author, follows. It is entitled, "The Artificial Production of Subsoil Water." The amount of natural subsoil water that is produced over any given area depends upon the porosity of the soil and the volume of the rainfall. The rain-water may be, and often is, replaced for agricultural purposes by artificial irrigation. In the neighbourhood of Stralsund there is a wide extent of level land, with an unretentive surface-soil, but the rainfall is too small to

[1] Minutes of Proceedings Inst. C.E. vol. xc. p. 511.

furnish the necessary volume of subsoil water for the requirements of the town. Abundance of water to replace the rainfall exists in the Borgwallsee or the Pütterteich. It is shown that the country in the neighbourhood of Langenberg would be best adapted for irrigation purposes, and the questions to be considered are:—1. Whether the yield of a natural filter-bed would become gradually exhausted, in the same way as that of an artificial filter-bed; and 2. Whether the water would sink into the soil too deeply to be recovered, or would flow away entirely over the surface. Reference is made to the results of irrigation at English sewage-farms and on the plain of Gennevilliers, in disproof of the former of these assumptions, and some experiments, carried out by the Author and Professor Scholz, are quoted to show that the water passing into the subsoil would encounter, over the whole of the proposed area, a substratum of impervious loam. The quantity of water which would be applied in the course of the year over the area of the proposed beds (4 hectares) would amount to a total stratum 35 metres in thickness, while the annual rainfall is but 0·60 metre for the neighbourhood of Stralsund, *i.e.*, 1·7 per cent. of the water to be used for irrigation. Experiments with the gravelly sand of the district show that, with the maximum percolation, an area of only 1,350 square metres would suffice to yield the estimated daily volume required of 5,000 cubic metres; but assuming an actual percolation of only 0·7 cubic metre, or about 20 per cent. of that ascertained by experiment (namely, 3·72 cubic metres of water), and taking an area sufficient to deal with the daily volume needed on one day only in five, in order to permit of the aeration of the soil in the intervals, a total surface of 3·6 hectares would be required. To guard against frosty weather, the Author supposes that a considerable depth of water might be stored in the subsoil, and he shows that the temperature of this water, both in winter and in summer, would be much better adapted to domestic requirements than that obtained from artificial filter-beds.

G. R. R.

The Changes in the Water of the Spree, Outside of and in its Passage through Berlin. By Dr. G. Frank.

(Zeitschrift für Hygiene, 1887, p. 355.)

Attention is called to the increasing pollution of rivers, and to the attempts which originated in England, and have since been made in most other populous countries, to find remedies for the evil. This question has been taken up on somewhat different grounds in Germany, in consequence of the investigations of Pettenkofer and others, pointing to the connection of cholera and typhoid fever with excremental impurities in the soil. The theory of Emmerich, which inculcated the harmless nature of highly-

diluted excreta, when mixed with river water and used for drinking and domestic purposes, quieted for a time the objections which were raised to the discharge of sewage matters into rivers; but when, in course of time, the doctrine of the propagation of diseases by means of germs, which might be conveyed in the drinking-water, gained acceptance, the pollution of rivers once more excited serious apprehensions. Only two important German investigations, extending over a lengthened period, into the character of river-pollution, have hitherto been published. The first was by Brunner and Emmerich, in the years 1874–75, relating to the Isar and its flow through Munich. They employed the chemical methods in use at that date, and laid chief stress upon the amount of chlorine and organic matters found to be present. Although in certain parts of the river the quantity of sewage was very considerable, they were able, as the general result of their analyses, to pronounce that, in the absence of any serious industrial pollution, even if the whole of the excreta of the city were discharged into the Isar, the river would, in consequence of its rapid flow and comparatively large volume, be uninjured.

Hulwa, in the course of the years 1877–81, examined the waters of the Oder in and outside Breslau, and he also employed the ordinary chemical tests, but he adopted the albumenoid ammonia process of Wanklyn and Chapman for the determination of the organic matters, and he examined the different samples microscopically, in accordance with the practice at that time in vogue. Adopting the standards of purity which had been laid down previously, he showed that the river was already impure before it reached Breslau; that in its passage through the town it gained considerably in the amount of impurities, but that after a flow of 32 kilometres, in consequence of its great self-cleansing powers, the river water had again become pure, and that neither by chemical tests, nor by the use of the microscope, was it possible, at this distance from the town, to demonstrate any sewage admixture, or to prove that the water was in any way different to that taken from the Oder above Breslau. Since these investigations, the whole system of water-analysis has been changed, in consequence of the introduction of the bacteriological tests, and the Author states that he has therefore deemed it expedient to undertake an examination of the Spree water on this new plan. His tests have been conducted at regular intervals from April 1886 to March 1887, on the river water both within and beyond the city of Berlin.

The inquiry is prefaced by a brief sketch of the history of the pollution of the river, from the end of the last century to the time of the adoption of Hobrecht's drainage scheme in 1875. Up till the 31st of March, 1887, 17,817 blocks of buildings had been connected with the sewers, and as, at the last census, the average population per block in Berlin was sixty-five persons, it may be assumed that the excreta of 1,158,085 inhabitants was under treatment at that date. The number of blocks connected with the

sewers during the year 1886–87 was 1,566, or the number of the contributory population on the 1st of April, 1886, may be set down at 1,051,635. From an examination of those radial systems, which are still incomplete, and of the numbers of blocks not yet connected with the sewers, the Author estimates that in the year 1886–87 a population of somewhat under 250,000, or say one-fifth of the inhabitants, was unprovided with arterial drainage. By various imperfect means a considerable proportion of the liquid dejections of this large section of the inhabitants finds its way into the river. By reference to a plan the distribution of the radial systems, of the outlets into the river, and of the general course of its flow, are explained. The discharge of the Spree and its tributaries in cubic feet and cubic metres, is set forth in a Table giving the mean volumes for each month in the year, varying from 23 cubic metres per second in February to 40 cubic metres per second in September. For the purposes of the inquiry samples of the Spree water were collected at fifteen places indicated on the map, chosen with reference to the junction of tributaries, the storm-overflows, &c. For the first nine months samples were taken every alternate Wednesday; during the last three months only on the first Wednesday in each month. The times and methods of taking the samples are described; the bacteriological examination always commenced within two to three hours after the water had been taken from the river.

The chemical analyses were carried out on the system pursued at the Hygienic Institute for the analysis of drinking water; the quantitative tests were for the residue dried at 110° Centigrade, chlorine, chameleon solution required for the oxydation of the organic matters, for lime, and in the majority of cases, also, for the ammonia; the qualitative tests were for sulphuric acid, nitric acid, and nitrous acid. Only in one instance was a quantitative test for nitrous acid required. The bacteriological examination was conducted upon the usual plan. In certain parts of the river the bacteria were so abundant that it became impossible to count the colonies from 1 cubic centimetre and 0·5 cubic centimetre spread on the gelatine surfaces in the usual way. In these cases a system of dilution was adopted by the Author which gave good and uniform results. A series of Erlenmeyer flasks were filled each with 100 cubic centimetres of ordinary drinking-water, and the contents were sterilised by exposure during several hours to a jet of steam at 100°. 1 cubic centimetre of each sample to be tested was introduced into one of these flasks, and by this means a dilution thereof, together with the bacteria therein contained, to the extent of 1 part in 100 was obtained. The examination of the water was then carried out in triplicate. One gelatine plate was cast representing 1 cubic centimetre of the water, a second with 0·5 cubic centimetre, and a third with the dilution to the $\frac{1}{100}$ of a cubic centimetre. The following Table is given to show how uniformly the results thus obtained tally with those furnished by the undiluted samples:—

River-water from Lesser Stralau Street.

Date.	1 Cubic Centimetre.	0·5 Cubic Centimetre.	0·01 Cubic Centimetre.
13 March	18,518	10,800	208
15 „	4,950	2,840	45
16 „	5,940	..	63
17 „	11,120	..	114
18 „	7,400	3,870	96
19 „	11,300	4,680	110
20 „	6,300	3,500	75
22 „	7,100	3,800	82

All previous experimenters have founded their opinions as to the character of polluted waters, and the extent of their subsequent purification, chiefly upon chemical grounds. A few only, as for instance, Hulwa and Girardin, have taken also into account the presence of certain low forms of vegetable and animal life which are found in impure water, but are absent in that which is unpolluted. The Author states that we have now at our disposal a knowledge of the more important micro-organisms which affect the character of a potable water, and a ready means of ascertaining their presence, and the same considerations which have to be taken into account when testing a sample of drinking-water must have weight when the quality of a river-water is being investigated. In both cases the bacteriological results must have a proponderating influence over the purely chemical tests.

After passing through Berlin the Spree flows past Spandau and unites with the Havel, which spreads out into a species of lake (the Wannsee), from which it subsequently issues as a narrow stream near Potsdam. Even before it reaches Berlin, the Spree is greatly polluted, and from a series of twenty-one observations taken at the Stralau Waterworks, the results of which are set forth in the form of a Table, it appears that while on the 6th April, 1886, there were 17,000 bacteria per cubic centimetre, the number had sunk on the 4th May of the same year to 750; these are the highest and lowest results. The amount of chlorine varied between 28·4 milligrams per litre in October and 14·5 in May. The tests, fifteen in number at each date, of the samples of river-water are contained in a series of twenty-two Tables which give the solid residue, lime, ammonia, oxydisability, chlorine, and number of germs capable of development on gelatine from 1 cubic centimetre of water. The general results, as set forth by the Author, show the rapid and regular increase in bacteria, as also in chemical impurities during the flow of the river through the town and past certain of the suburbs, under conditions which he examines in detail. On reaching the lake-like Havel, a deposition of the suspended matters and a vast diminution in the number of bacteria is uniformly observed, and the Author explains that a river in flowing through a lake is known to part with a large proportion of its impurities, for various

reasons to which allusion is made, and the whole question of the self-cleansing power of rivers is discussed. In conclusion, it is shown that in consequence of the existence of this lake in the course of the Havel, the city of Berlin is placed in a highly favourable position, and one enjoyed by no other large town in Germany. Certain exceptional cases during the period the river was under observation are individually considered, and the Author states in conclusion that the effects of a polluted water-supply upon the health of a community have not yet been determined, though recent investigations have shown that germs peculiar to certain named diseases are capable of a more or less protracted existence in water.

G. R. R.

Pumping-Station at Jürgensfeld. By — TOLLE.

(Zeitschrift des Architekten- und Ingenieur-Vereines zu Hannover, 1887, p. 350.)

The St. Jürgensfeld Level, in the district of Osterholz and province of Hanover, lies a few miles to the north of the city of Bremen, and comprises an area of about 11,120 acres, bounded by the rivers Wörpe, Wümme and Hamme on the east, south and west respectively, and by moorland on the north. These rivers, after their confluence together, form the Lesum, which falls into the Weser at Grohn Vegesack. The Level is almost a dead flat, liable to inundation in summer, and invariably flooded to a considerable depth every winter. The central portion is, with the exception of a few houses around the church of St. Jürgensfeld, uninhabited, the villages, of which there are about fifteen, being scattered along the northern border. These villages are built upon artificial mounds sufficiently high to be clear of the floods. The pumping-works described by the Author were instituted, not for the prevention of the winter inundation, which is regarded as rather favourable than otherwise, owing to the fertilizing sediment deposited, but for ensuring that the Level, already protected by dams (*Sommerdeiche*) high enough to keep out the summer floods, should be drained sufficiently early in the spring, and afterwards kept clear of water for the period requisite for the development and harvesting of the crops. Practically the whole is grass-land, about half the area being meadow and the remainder pasture.

The rivers skirting the Level are subject to tidal influence, which extends up the Lesum, Wümme and Wörpe to about 2 miles above the mouth of the latter; as regards the Hamme, the adjacent land is protected against the summer floods by closing a large sluice-gate near Ritterhude, a short distance above the confluence of this stream with the Lesum.

Ample provision already existed for the escape of the water from the Level, viz., by eight dam-sluices (three of a width of 10 feet 8 inches); but the requisite subsidence, early in the season, of the rivers Hamme and Wümme could not be depended upon,

especially of late years, owing to the improvements in the Upper Weser being executed prior to the corresponding works in the Lower Weser.

The levels above a datum are given of the highest, the average, and lowest water-levels on the Weser, Hamme and Wümme at various points, and also the average surface of the land in question. This latter is + 3·54 feet, the highest known level of the Weser at Vegesack + 17·18 feet, and of the Hamme and Wümme + 13·77 feet. The lowest known level of the Weser at Vegesack − 0·82 foot, of the Hamme at Ritterhude − 0·49 foot, and of the Wümme at Höftdeich + 0·26 foot.

The crest of the dams protecting the area against the summer floods vary from + 10·17 feet at the south-western end of the Level to + 13·12 feet at the eastern end in the vicinity of the upper reaches of the Wümme; but as regards the Hamme, of which the flood-level is lower, the crest of the dams skirting it are (above the Ritterhude sluice) carried up to a level of only + 7·21 feet. In 1882 it was decided to erect a pumping-station, and as the level of the dams was to remain unaltered, the design was based upon the assumption that pumping operations could only be commenced when the water had subsided to a level of, say, + 6·90 feet, or 0·33 foot below the crest of the upper Hamme dam.

The date fixed for the commencement of pumping operations in each year (river water-level permitting) was the 1st of April, the pumping to be continued until the water had been lowered to + 1·97 foot, or 1 foot below the surface of the lowest lying land. The pumping machinery to be capable of laying dry the Level by the 20th of May, excepting in extraordinarily wet seasons (such as 1867). Also that the pumps should in summer be capable of clearing off the greatest rainfall of any one day in a period of four days.

The data upon which the calculations were based are given. Amongst others, the area to be drained was 10,131 acres; the period of drainage operation forty-five days; highest level of water + 6·90 feet; average level of ground + 3·54 feet; depth of water 6·90 − 3·54 = 3·36 feet (exclusive of that below surface of land); extreme rainfall for forty-five days (less evaporation) 4 inches; springs, leakage, &c., 1·57 inch; mean lift, 1·42 foot; greatest lift, 7·21 feet; amount of water to be raised in forty-five days, 11,005,000,000 gallons; the greatest rainfall for one day (summer) assumed as 247,612,500 gallons.

The power, therefore, for fulfilling the first condition, viz., the drainage of the Level in spring within forty-five days, would be, assuming twenty-two working hours per day, the lifting of $\frac{50{,}000{,}000}{45 \times 22 \times 60 \times 60}$ = 14 cubic metres, or 3,082 gallons per second, to a height of 1 foot 5 inches (80 HP.); and as regards the requirements in summer, the lifting of 1,125,000 cubic metres, or 247,612,500 gallons, divided over a period of four days, each of twenty-two hours, to a height of 2·2 metres, or 7 feet 3 inches (114 HP.).

It was decided to erect engines of 329 indicated or 263 nominal HP., equal to a pumping power of 114 HP. The pumping-station was erected near the lowest lying ground, comprising three centrifugal pumps, each having two suction- and one delivery-pipe worked by compound engines. The engine-house and chimney are of masonry founded on a bed of concrete 2 feet 9 inches thick, and the machinery attendant's house is of timber-framing. The collecting-channel is, for a distance of 820 yards from the pumps 50 feet broad and 5 feet deep; beyond that the breadth is reduced to 33 feet.

It was specified that each pump should be capable of lifting 1,027 gallons to a height of 1·41 foot, with a maximum consumption of 2·31 lbs. of coal per indicated HP. per hour, and with a lift of 8·2 feet, a quantity of 209 gallons.

The results of nine days' experimental trials with the engines are given, including the consumption of coal, &c.; also details of the cost of machinery, buildings, &c., viz.:—

Machinery—	£.	s.
Three high-pressure tubular boilers, each with 904 square feet (84 square metres) heating-surface, and a pressure of 90 lbs.	1,012	10
Three centrifugal pumps (70 to 85 revolutions per minute) and their compound engines, each with cylinders of 13⅝ inches and 23½-inches diam., and 27⅝-inches stroke	2,650	0
Three delivery-ducts of 4 feet 11 inches diameter, and six suction-ducts of 3 feet 6 inches diameter	394	15
Valves of delivery-ducts	142	10
Valves of suction-ducts	110	0
Two steam feed-pumps	70	0
Pipes, gratings, travelling-crane, tools, &c.	371	17
	£4,751	12

Buildings, &c.—	£.	s.
Engine-house (including £650 for foundations)	3,100	0
Machinery-attendant's house and smithy	500	0
Collecting-channel, embankment, piling and concrete in channel leading to and from pump-ducts	4,150	0
	£7,750	0

or a total outlay of say £12,500 (250,000 marks).

The details of the annual working cost are as follows, viz.:—

	£.	s.	d.	Marks.
Interest on £12,500 (250,000 marks), at 5 per cent.	625	0	0	12,500
Pay of Inspector	37	10	0	750
„ Book-keeper	22	10	0	450
„ Machinery-attendant	50	0	0	1,000
„ Stoker	15	0	0	300
Cost of coal (250 tons)	210	0	0	4,200
„ Lubricants and sundries	80	0	0	1,600
	£1,040	0	0	20,800

The amount chargeable per acre is thus about 2*s*. (5*s*. per hectare). Each farmer averages an area of 86½ acres, and therefore has to pay about £8 15*s*. (175 marks).

The works were completed in 1885. The Paper is accompanied by a map of the district, and diagrams of the pumps, buildings, &c.

D. G.

Action of Water on Galvanized Iron Pipe.

By W. R. Nichols and J. K. Russell.

(Journal of the Association of Engineering Societies, New York, 1888, p. 12.)

In this Paper, which was read before the Boston Society of Civil Engineers, are given the results of experiments made to show the quantity of zinc actually taken up by Boston water in galvanized service-pipes, under ordinary conditions. Though it is usually possible to detect zinc in water which has passed through any considerable length of zinc-coated pipe, yet it is believed that the proportional quantity either in suspension, as a hydro-carbonate, or in solution, was too inconsiderable to be objectionable from a sanitary point of view.

The experiments were made with a length of 39 feet of ½-inch galvanized pipe, connected with the water-service of the building, in such a manner that the water in the pipe could at any time be displaced by fresh water, without allowing air to enter. Zinc was found, in solution and in suspension, wherever water had stood in the pipe for from seven to seventy hours. Water that had remained in the pipe for several days did not contain a greater proportion of zinc in solution than for shorter periods, but the quantity of zinc in suspension was augmented. The water held in solution 0·3 to 0·6 parts of zinc per 100,000 parts of water, and in suspension from 1·5 to 2 parts per 100,000 parts of water; or, 0·3 grain per gallon in solution, and 1·0 grain per gallon in suspension. In water in regular flow, no zinc was discovered; but when the rate of flow was reduced to 1 quart per hour, 0·9 part per 100,000 was found in solution and suspension.

It is inferred from these observations that the zinc coating is slowly but continuously dissolved. In order to determine the thickness of the coating and the depth to which it penetrates the iron, some rods of wrought-iron, 6 inches long, were turned off for a length of 4 inches, to a diameter of 0·901 inch, and coated in the usual manner to a diameter of 0·905 inch, showing an increase of $\frac{4}{1000}$ inch in diameter, or a ring $\frac{2}{1000}$ inch thick. Three rods thus treated were reduced in the lathe to their original diameter, and the turnings consisted of zinc and iron in the following proportions:—

	Zinc.	Iron.
No. 1	97·08 per cent.	2·19 per cent.
No. 2	96·42 „	1·87 „
No. 3	97·20 „	1·70 „

On still further turning down the rods, below the normal diameter, zinc was discovered in sensible proportions, showing that it does slightly penetrate the iron, forming an alloy.

The insoluble precipitate formed by the action of water on zinc was found, when analyzed, to consist of zinc, water, and carbonic acid, forming a zinc hydrocarbonate.

Tests were also made of a pipe coated with a composition of lead, tin, and antimony; and of a brass pipe. Lead and tin in the former, and zinc and copper in the latter, were found in solution.

D. K. C.

Heating by Steam. By C. E. Jones.

(Journal of the Association of Engineering Societies, New York, 1888, p. 14.)

A Paper on "Steam-Heating" was read by Mr. Jones before the Engineers' Club of St. Louis, U.S.A., in November, 1887. In 1879, the buildings of Washington University, which had previously been heated by cast-iron furnaces on the old style, were fitted with modern steam-plant instead. There are three steam-boilers, 5 feet in diameter, 16 feet long, each containing thirty-six 4-inch flue-tubes, and each presenting 750 square feet of heating surface, with 24 square feet of grate-area. The work of these boilers is recorded for the season 1884–85, an extremely cold season, extending from October 1 to June 10, the average temperature being 5° Fahrenheit below the normal temperature. In January and February the external temperature was on many days below zero, when the steam was kept up in all the buildings night and day. Nine buildings, having a total content of 3,241,899 cubic feet, were heated from 19,815 square feet of pipe-heating surface, or at the rate of 164 cubic feet per square foot of surface, with a consumption of 39,014 bushels of bituminous coal for two hundred and sixteen days; or 1·038 cubic foot of capacity for 1 lb. of coal for the whole season. The consumption of coal on 72 square feet of fire-grate frequently amounted to 2,400 lbs. per hour, or 33⅓ lbs. per square foot: equivalent, at the rate of 6 lbs. of water per lb. of coal, to 14,400 lbs., or 231 cubic feet of water evaporated per hour, into steam of 45 lbs. pressure per square inch. The lengths of time during which the buildings were heated were as follows:—

	Hours.
The university, including the gymnasium, observatory, and chemical laboratory	3,051
Manual training school, both buildings	2,510
Smith academy	1,139
Museum of fine arts	1,315
Second Presbyterian church	735
Total number of hours	8,750

The total cost of the steam-heating apparatus to the University, comprising land, boilers, fittings, heaters and pipes, amounted to £3,550.

The pipes are 3 inches and 4 inches in diameter. There are nearly 1,000 feet each of steam- and return-mains. Nearly all the piping was originally laid in pine boxes of 2-inch lumber, well tarred inside and outside. The pipes were wrapped in asbestos paper, hair-felt ¾ inch thick, and strong wrapping-paper, bound with strong twine. The free space in the box was filled with coke-breeze. At the end of a few years, the pipes on examination were found to be in fairly good condition; but the boxing was badly rotted where it was only a short distance (about 3 feet) below the surface. The top was split for its whole length, and crushed inwards. The pipe-covering had rotted away to a large extent. The coke-breeze appeared to have been ground down, in consequence of expansion and contraction of the pipes.

The pipes to the Art Museum were laid in "gutter-pipe," or sewer-pipes in halves laid together, and packed in a paste of charcoal and cement. This system did not succeed, as the longitudinal joints were opened by expansion and contraction, and the charcoal filling absorbed moisture from the earth. The moisture was evaporated by the hot pipes, and these were rapidly destroyed.

Ultimately, it was decided to lay the pipes on a flat floor of hard-pressed bricks in cement, and well grouted, and to cover them with 21-inch gutter-pipes in cement, forming an arch over the pipes. If water got into the enclosure, it had the opportunity of running away to the sewer-connections without wetting the pipes, which were carried on rollers. The confined air formed the only non-conducting medium. The cost of protecting the pipes in this manner has been about 5*s.* 3*d.* per lineal foot. The value of the pipes is about 12*s.* 6*d.* per lineal foot.

D. K. C.

Biétrix's Steam-boiler, with Circulating Heaters.

By — Batault.

(Comptes rendus de la Société des Ingénieurs-civils, September 1887, p. 271.)

In this boiler, between the principal cylinder and the lower heater (*bouilleur*), three small heaters are placed directly over the fire-grate; so augmenting the surface exposed to radiant heat, and promoting internal circulation. This boiler has been submitted to test-trials, in comparison with a like boiler, without the addition of the small heaters. The unit of comparison was the quantity of coal consumed for the development of 7¼ millions of foot-lbs. of work done by the engine, supplied with steam from the two boilers successively in the course of one month's trial of each. The results showed that, whilst in the boiler of ordinary

design, 18·6 pounds of coal was consumed per million of foot-lbs., in the boiler fitted with supplementary heaters, 15·6 lbs. was consumed for the same duty; showing an economy of 16·4 per cent.

D. K. C.

Comparative Evaporative Experiments with Donneley's Patent Grate. By C. SCHNEIDER.

(Zeitschrift des Verbandes der Dampfkessel-Ueberwachungs-Vereine, 1887, p. 166.)

These experiments were made at the new Natural History Museum at Berlin, with two Lancashire boilers, one having an ordinary grate and the other a grate on Donneley's system. In other respects the two boilers were exactly alike.

In Donneley's furnace the fuel is inclosed between very steeply inclined grate-bars on the outside, and a series of vertical water-tubes in connection with the boiler on the inside next the latter; on either side is a brick wall, the whole constituting a kind of hopper, of which there are two, one opposite each flue. Between the water-tubes and the front plate of the boiler is a short space closed at the top by a brick arch, and at the bottom by a hinged flap for removing ashes.

The whole is enclosed in a cast-iron casing, having a damper for the admission of air and a fire-door. The grate is fed from a hopper above it containing the fuel; the grate-bars are cooled by water. The object of the experiments was:—(1) To compare the efficiency of the Donneley grate with that of the ordinary arrangement; and (2) to test its capacity for consuming smoke.

Four kinds of coal were used, large coal, nut-coal (both from Upper Silesia), anthracite and lignite.

The following were the dimensions of the boilers:—

	Feet.	Inches.
Length	26	3·0
Diameter of shells	6	6·7
„ flues	2	3·56

The boiler with ordinary grate had

	Square feet.
Heating-surface	679·55
Grate-area	26·91

that with Donneley's grate

	Square feet.
Heating-surface	679 + 67·49 = 747·04
Grate-area	19·375

The feed-water during the experiments was measured in tanks the contents of which were determined before and after the tests by direct weighing. Each boiler had its own particular feed-pipe. Average samples of the fuels were analysed, and their heating power calculated from the constituents. The products of com-

Nature of fuel used	Large Coal.		Nut Coal.		Anthracite.		Lignite.	
Description of grate	Donneley.	Ordinary.	Donneley.	Ordinary.	Donneley.	Ordinary.	Donneley.	Ordinary.
1. Duration of experiment . . hours	9¾	8	7¾	8	9	9	8¾	4
2. Fuel burned . . . . . lbs.	4975·78	2669·77	2539·74	3681·72	3443·58	2764·55	9528·30	5555·51
„ „ per hour and square foot of grate area . „	26·36	12·41	16·91	16·10	19·74	11·41	56·24	51·65
3. Water evaporated . . . . „	38,137	17,767	20,738	24,881	27,670	19,751	24,960	13,133
Temperature. . . . ° Centigrade	12	12	12	12	13	13	12	12
Boiler-pressure . . lbs. per sq. inch	56·89	57·33	67·77	67·77	62·18	57·92	63·21	66·15
4. Gases; proportion of CO_2 per cent.	14·78	10·35	15·06	10·50	15·00	12·60	15·9	12·5
Temperature. . . . ° Centigrade	259	287	197	240	201	206	264	202
5. Evaporation per lb. of fuel. . lbs.	7·66	6·05	8·16	6·75	8·03	7·14	2·62	2·36
„ „ „ from and at 100° . . . . . „	9·14	7·22	9·76	8·07	9·58	8·51	3 13	2·81
Evaporation per square foot of heating surface per hour . „	5·241	3·299	3·586	4·311	4·120	3·231	3 819	4·399
6. Heat utilized per lb. of fuel, B. T. U.	8836·2	7668·0	9430·2	7799·4	9250·2	8211·6	3004·2	2685·6
Efficiency; heat utilized per lb. of fuel, per cent.	69·3	60·1	73·2	60·5	76·2	67·6	68·6	61·3

bustion were analysed with regard to the quantity of carbonic anhydride contained in them, and the temperature of the gases in the smoke-stack measured. The results of these analyses and measurements are given in detail in the original, and the preceding Table contains some of the more important.

The results in every case show a marked superiority where the Donneley grate was employed, and the latter proved efficient as regards the prevention of smoke.

G. R. B.

On the Friction of Non-Condensing Engines.

By Prof. R. H. Thurston.

(Transactions of the American Society of Mechanical Engineers, 1887, p. 86.)

The Author had for many years doubted the accuracy of De Pambour's assumption that the total resistance (R) to be overcome by the engine-piston $= (1 + f)\,R_1 + R_0$,

where R_0 = resistance of engine running free, and under no other load than its own friction.

R_1 = resistance coming upon it as a useful factor of its work.

f = coefficient measuring proportion of increased friction due to load.

It having never been settled whether f is constant or variable, the Author commenced experiments in the winter of 1883–84 with a view to settle that question. The investigation was made on a "straight line" engine, having a single cylinder, 9 inches diameter and 14 inches stroke; and in order to verify the satisfactory results obtained in this trial, a repetition of the experiments was made upon another "straight line" engine of similar pattern to the first, but having a smaller cylinder, and a third series took place in connection with an engine of different make. The conclusions set forth hereinafter are based upon the concordant results of the three series.

A special form of reducing-gear is described in connection with the indicators, and the arrangement of electrical and other testing- and recording-apparatus is fully set forth.

The Table of results of the first trial shows that the law of De Pambour does not hold good, and that it is as nearly correct to say that the friction of the engine is constant as otherwise. A curve of friction is shown in connection with this series of experiments, and the total friction in the case of the third trial may, it is said, be taken as constant, without any serious error.

In connection with the second trial, a special set of experiments showed that rise in steam-pressure produced increase of frictional

resistance of the engine, useful load and the speed remaining constant. This result may appear inconsistent with the foregoing conclusion, but the apparent discrepancy is probably due to variation produced by the governor in the distribution of steam. This matter is considered in detail in the Paper, and a suggestion as to valve-setting is made, which is intended to secure greater efficiency of the engine.

Several indicator-diagrams and curves are given, and it is pointed out that increase of load frictionally affects only the "line of connection," *i.e.*, shaft, crank-pin, and cross-head, and the friction of these parts is but, say, from 10 per cent. to 20 per cent. of the total friction of engine, for the remaining 80 per cent. or 90 per cent. consists of resistances due to the motion of piston-rod or rods through stuffing-boxes and in guides, the friction of eccentrics, of piston-rings on the cylinder-surface, and often other parts, which are independent of variations of load.

The Author summarizes his conclusions, stating that the friction of this class of non-condensing engine is sensibly constant at any given speed and steam-pressure, at all loads, and is at different speeds entirely independent of the magnitude of the load. Several minor considerations are discussed, and the expression

$$R = R_1 - R_0$$

is put forward as sufficient for practical purposes,

R being total resistance, as shown on indicator diagram,
R_1 „ resistance due to external load; *e.g.*, as measured by a Prony brake, and
R_0 „ resistance of the unloaded engine, as shown by a "friction-card" from indicator.

These conclusions are only applicable to one class of engine, for it is not improbable that the condensing-engine may be subject to quite different laws.

F. W. Q.

The Application of Liquid Fuels to Marine Boilers.

By — BUSLEY, Marine-engineer, Kiel.

(Zeitschrift des Vereines deutscher Ingenieure, 1887, p. 989.)

In this Paper the Author reviews the whole subject of the use of liquid fuel up to the present date, more especially with regard to its application to the boilers of war-vessels. He commences with a short general historical review of what has been done up to the present time in this direction in various countries, and so far only in Russia has the use of liquid fuel for the production of steam attained any considerable proportions.

Under the heading of "Liquid fuels hitherto employed," the various oils which have been tried as fuel are enumerated, their heating-power, specific weight, temperature of ignition, total output and cost are given and compared with those of coal, together with the estimated quantity required per annum in each case to supply the vessels of the whole world. In every instance the cost of liquid fuel at present prices in Germany is much in excess of that of coal, but the Author is of opinion that for naval purposes increased expense is not prohibitive, in view of the many compensating advantages to be obtained by the substitution of liquid for solid fuel. Taking the cost of coal—good Westphalian—as unity, the relative cost of various liquid fuels is as follows:—Crude Petroleum, American, 4·17, Caucasian, 2·5; refuse of illuminating oils, American, 4·86, Caucasian, 2·91; refuse of lubricating oils, 1·94, shale oil, 2·91, and tar, 1·50.

"Furnace arrangements and their results" are next considered. The Author classifies the various types of furnace designed for burning liquid fuel under three heads. (1) Hearth or grate furnaces in which the fuel is ignited in its ordinary liquid state; (2) gas furnaces in which it is first converted into gas, and (3) spray furnaces, in which it is introduced in the form of spray.

The construction of the different varieties of furnace hitherto tried are described, and the results obtained given, while the efficiency of the various types is compared.

An account is given of some recent experiments in 1887, carried out by d'Allest on torpedo-boat boilers with an apparatus of his own, of the injector class, for burning oil-refuse. These trials were made both with natural and forced draught, and the results are given in a tabular form side by side with those obtained by Guillaume and Thornycroft, using respectively briquettes and coal as fuel; they show a marked superiority of the oil.

The liquid fuel evaporated 13·25 lbs. of water at 100° Centigrade to steam of 3 atmospheres pressure, and the briquettes only 9·68 lbs., under the same conditions; with oil-refuse too, the evaporation per square foot of heating-surface was greater than with coal. The injector type of spray-producer appears to give the most economical results and is less liable to become choked than other forms. According to the experiments of d'Allest, when using injectors for ordinary compound engines 0·7 to 0·8 kilograms (1·54 to 1·76 lbs.) of oil is required per indicated horse-power per hour.

In Part IV, the Author treats of the management of spray-furnaces under four heads:—(*a*) Getting up steam, (*b*) avoidance of interruptions, (*c*) leaving off firing, (*d*) prevention of accumulation of salt in the boiler.

On steamers the simplest method of raising steam is by help of one of the boilers used in the harbour for working cranes or other purposes; but in the absence of this means, steam of sufficient pressure is soon produced by firing temporarily with wood. An arrangement of Tarbutt's for facilitating this operation is described.

Where, as in some of d'Allest's experiments, air instead of steam is employed for the injector, a small reservoir may be used, which is charged before stoppage of the engines with sufficient air, to get up the necessary pressure at starting to work the injector.

In shutting off the injector the oil-supply must be first stopped, and afterwards the steam.

With respect to the objections raised in some quarters to the use of oil-fuel on the ground that the fresh water required for the injection-steam has to be replaced by salt water, the Author shows that in comparison with the salt water always necessary to compensate for loss in the condenser, this amount is practically of no importance.

G. R. B.

Hot-Air Engine.[1] By — Bénier.

(Dingler's Polytechnisches Journal, vol. cclxvii. 1888, p. 193.)

The above article describes a hot-air engine with some novel features of construction for obtaining a high useful effect directly from the burning fuel. The particular engine described is of 6 HP., and consists essentially of a vertical working-cylinder, with a hollow plunger attached by a rod to a horizontal working-beam; at the opposite end of the beam is a connecting-rod, acting on a crank-shaft in the manner usual in beam engines; the crank-shaft is provided with a fly-wheel, and runs in bearings fitted in the base of the engine; from this crank the horizontal cold-air pump is worked by means of a lever and rods; slide-valves worked by cams admit the cold air to the pump, and thence to the working-cylinder. At the bottom of the working-cylinder, a small furnace is formed by a lining of plumbago or graphite. The cold air is admitted from the pump at a pressure of about 15 lbs. per square inch, when the pump-piston is at the end of its own stroke and the working-plunger at mid-stroke. Part of the entering air from the pump is admitted below the furnace-grate, and part above in an annular space around the working surface of the plunger, thus preventing the burnt gases from coming into contact with the wearing surface of the plunger. The furnace is automatically fed by a revolving cup-wheel, arranged to pick up a piece of coke and to allow the piece to drop down a shoot into a cavity in a sliding valve below. The valve is alternately in communication with the shoot to receive the coke, and with the furnace into which the coke drops. A governor is provided to regulate the speed. The conditions of working are stated to be much as those of a steam-engine. The pump draws and delivers only cold air, and as part of this goes into the upper part of the working-cylinder, it tends to keep the working-surfaces

[1] Minutes of Proceedings Inst. C.E. vol. lxxxix. p. 516.

at a comparatively low temperature, from 200° to 240° Fahrenheit. The engine described was subjected to six-hour trials on a brake loaded to different horse-powers, and gave a consumption of from 3·3 lbs. of coke per HP. per hour with light loads, to 2·4 lbs. with heavier loads. The article is illustrated by a plate showing the engine in detail.

H. H. P. P.

On Fire-Boats. By William Cowles.

(Transactions of the American Society of Mechanical Engineers, 1887, p. 182.)

The Paper relates to the design, dimensions and performance of five floating fire-engines; three of which vessels were designed by the Author, and built (as also was the fourth) in the United States, the fifth being Messrs. Merryweather and Sons' fire-boat "Merryweather," built in London for use in Alexandria, Egypt. Nine sheets of drawings of the three vessels designed by the Author, and a comparative table of dimensions of the vessels mentioned in the Paper, are appended thereto.

As far as is known to the Author, the wooden steamer "Seth Low," built for the Brooklyn fire department in 1885, was the first self-propelled floating fire-engine of high power, as distinguished from tugs and like vessels not specially built for fire service. Since that date, two similar but improved wooden vessels have been built, one being the "Geyser," for Chicago, and the other a boat for Cleveland, Ohio. The latter vessel is fitted with the Kunstadter arrangement of propeller, in which the screw is carried by the rudder, and revolves in an aperture therein; connection between the screw and the tail-end shaft being made by a Hooke's joint. The adoption of this arrangement (which is fully illustrated) was necessitated by the crooked character of the river Cuyahoga, in which the boat works.

The writer considers the "Merryweather" to be a fire-boat of great capacity, considering her small size, but he denies her suitability for use in very large ports, such as London, her reported maximum fire-capacity being one $1\frac{3}{4}$-inch to 2-inch stream thrown 200 feet. It is pointed out that little $\frac{7}{8}$-inch to $1\frac{3}{4}$-inch streams are almost useless at a large fire, except to keep it from spreading, for they are vaporized before they can penetrate it, whilst a $2\frac{1}{2}$-inch to 3-inch stream will tear its way through walls, partitions, goods, &c., into the heart of a big fire, and break it up so that the small streams can operate on it effectively.

The main features in the design of a high-power fire-boat are the boilers and pumps, the hull and motive machinery being secondary matters; but manœuvring power and speed, in the order mentioned, are also very important items.

On account of its lightness, and for other important reasons, the "Scotch" boiler was adopted by the writer for the boats built

to his designs; data of weight and other matters are given, and suggestions as to the method of working fire-boats in connection with shore engines, and on the Holly and other systems, are given; and, finally, the writer from his studies and experience, has concluded that it is quite possible to build and equip, complete and ready for service, a small floating fire-engine with two to three 2-inch streams, suitable for a small port, for £4,170, and one of half this capacity for £2,920. This includes the cost of hose, pipes, nozzles, &c., which is always a large item.

F. W. Q.

The Walcher Coal-getting Apparatus.

By René Grey,

(Bulletin de la Société de l'Industrie Minérale, vol. i. 1887, p. 767.)

The object of this apparatus is the same as that of the Levet hydraulic wedge, viz., to supersede the use of powder or other explosives in fiery mines. It is self-contained, and complete in itself, and consists of two principal parts—the expanding mandrel for breaking down the coal, and the hydraulic pump or jack for obtaining the requisite power. These two parts are rigidly fixed together, and by a careful choice of materials the total weight has been kept down to 150 lbs., so that it can be easily handled by two men. All the principal parts are either of hardened and carefully-tempered steel, or of phosphor bronze.

The pump, which is of very neat and ingenious design, and not liable to injury, even in unskilled hands, is fully described and illustrated in the Paper and its accompanying engravings. All the working parts are self-contained, as in an ordinary hydraulic jack.

The breaking-down part proper is approximately of cylindrical form, circular at the front end, and slightly oval at the rear, where it is coupled to the pump. It consists of two movable cheeks and a central square part lying and sliding between them, the whole being of a suitable size to be easily introduced into a hole 5 inches in diameter and 3 feet 3 inches deep, bored in the upper portion of the coal, which, of course, has been previously undercut by hand or machine. In recesses between the cheeks and the sliding-block are six small toggles of hardened steel, of cylindrical shape with hemispherical ends, arranged three above and three below the sliding-block, and lying at an angle of 45°. The sliding-block is coupled to the piston-rod of the pump, and can be drawn back until the toggles assume a nearly vertical position (85°) and force out the upper and lower cheeks. As a pressure of 500 atmospheres, corresponding to 50 tons on the piston, can be easily obtained in the pump, and as the force of the toggles, unlike that of a wedge, increases enormously as they approach the vertical position, an

up-and-down force of from 200 to 300 tons can be very easily obtained. The friction is insignificant, being only that of the piston-rod in the stuffing-box, and of the toggles on their bearings.

When the apparatus is inserted in the hole ready for applying the pressure, its outer, or pump end is slung by a chain from one of the timbers supporting the roof, or from the standard which has been previously used for the drill, so as to save it from being injured by falling when the coal comes down. After the front portion has been wedged off, it may be inserted deeper in the hole, and the operation repeated.

Glycerine is by preference used for charging the pump, as it not only protects the working parts from rust, but also acts as a lubricant.

The apparatus has been in use since September last at the Sandwell Park colliery, near Birmingham, and at the Lilleshall Company's pit, Shifnal, and for a still longer period in several of the Westphalian collieries. It is now undergoing a special trial by the commission appointed to award a prize of 1000 ducats (£370) offered by the coal-owners in the Ostrau-Karwin district for the best substitute for explosives.

Besides detailed drawings of the apparatus, the Paper is illustrated by sketches of various methods of its application under differing conditions, and of the manner in which the coal is brought down.

W. S. H.

Note on the Bloomery Process at the Otschersk Ironworks.

By N. Haltzoff.

(Gorny Jurnal, 1887, p. 517.)

Only iron unsuitable for puddling is subjected to this process, which is carried on by the aid of wood charcoal. The bloom is hammered out into a single slab, which is then put into a reheating-furnace and rolled into sheet-iron, the manufacture of which is a specialty of these works.

Detailed working drawings are given of the bloomery furnace. The hearth is confined on all sides but the front. Each furnace is furnished with a heating-chamber, through which the waste gases pass before entering the stack. This chamber forms the back part of the furnace, and is also confined on all sides but one; it stands on a higher level than the hearth. Here the iron is heated to a red heat before coming to the hearth, and also the blast is heated by a branch pipe passing backwards and forwards through the chamber, before entering the twyer.

The actual hearth is made up of five cast-iron slabs, each of which has its peculiar name: one, the "bottom plate," forms the bed, at a slight incline, and is 2 feet 6 inches deep, 1 foot 7 inches

wide, and 2½ inches thick; the "lower twyer-plate" forms the twyer side of the hearth, and on it lies the twyer; it is 2 feet 3 inches long, and 1 foot 1 inch deep at the front, and 9 inches at the back, that being the inclination of the bed. The "contra twyer-plate" forms the other side of the hearth; the "back plate" the back, and the "slag-plate" the front. Besides these, there are two plates resting on the "back" and "contra twyer," plates called respectively the "upper back" and "upper contra" plates. The first five plates are kept in position by iron wedges. The bottom plate lies on iron rests, so as to leave a cavity beneath, which may be filled with water.

The twyer is made of copper, with an arc-shaped eye, 1 inch high by 1½ inch wide. The bottom of the twyer is made flat, for facility in setting. The distance of the eye from the bottom plate is 7 inches, and it protrudes 2½ inches into the hearth. The twyer rests partly on the "lower twyer plate," and partly on an iron slab which lays on the brickwork of the furnace, and it is also held in position by iron wedges and plates above. The nozzle is made of cast- or wrought-iron, and has a flat bottom; the end fits into the twyer, and is 3 inches distant from the eye of the twyer.

The blast is heated to from 60° Centigrade to 150° Centigrade, and is supplied at a pressure of about 2 inches of mercury; each furnace on the average requires 120 cubic feet of air per minute.

The framework of the furnace is made of iron. The following is an estimate of the cost of such a furnace:—

400 poods (6 tons 9 cwt. 3 lbs.) of cast-iron at 1 ruble 13 kopecks per pood	452·00
1,500 red bricks at 10 rubles per 1,000	15·00
150 white fire bricks at 50 rubles per 1,000	7·50
150 poods (2 tons 8 cwt. 43 lbs.) of white and red clay	3·00
8 poods (2 cwt. 65 lbs.) of sheet iron at 2 rubles 20 kopecks per pood	17·60
3 poods (108½ lbs.) of bar and angle iron at 1 ruble 65 kopecks per pood	4·95
One copper twyer (8 lbs. weight)	3·15
Labour	30·00
Total . . . . . Rubles	533·20

The blooms are forged by tilt-hammers. The weight of the head of the hammer is 50 poods (15 cwt. 25½ lbs.), the height of the fall 2½ feet, the number of strokes per minute sixty, and the weight of the anvil 550 poods (8 tons 17 cwt. 38 lbs.). These hammers are worked by 30 HP. turbines.

The process itself is carried on as follows:—If scrap-iron be used as well as pig-iron, it is thrown on the bed of the hearth, and pieces of red-hot pig-iron are let down upon it from the heating-chamber, the pig-iron placed up against the "contra twyer plate," and the whole is covered over with charcoal, and the blast put on. After about fifteen minutes the slag in the

furnace begins to melt, and, flowing on to the cool "bottom plate," partly solidifies. Then the pig-iron begins to melt into a pasty mass, and also settles on the bottom of the hearth. During this the workmen frequently separate the lumps of pig-iron from the "contra twyer plate," and bring them towards the twyer; while observing the progress of the operation, if necessary, add rich slag, and if the pig-iron becomes too stiff, more scrap-iron. In about forty minutes the pig-iron is sufficiently heated, and the superfluous slag is drawn off. The blast is diminished, and the whole mass turned over, so that what was before at the bottom is now at the top. The slag which was at the bottom is broken off with hammers, and the workmen collect the whole mass round the twyer and cover it with charcoal, and the blast is again increased. This turning over takes about ten minutes. The next operation consists in bringing up to the top again that iron which has melted and run to the bottom of the hearth. This is continued until the whole mass has been turned over two or three times. During this operation, which lasts about forty minutes, the iron is acted on both by the blast and the melted slag on the bottom of the plate. The whole mass is then gradually melted, and settles on the bottom of the hearth, which takes about thirty minutes. At this time the blast is at its strongest, and the remaining portion of scrap-iron is added in two lots. The last operation, which takes about fifteen minutes, consists in collecting all the iron in one bloom, over which wet slag is thrown. The blast is then stopped, and the bloom taken out in lumps to the hammer. The whole operation takes two and a half hours. One furnace is worked by two skilled men and a labourer, who turn out three blooms in a shift. The charge of pig-iron and scrap-iron is $6\frac{1}{2}$ poods (2 cwt. $1\frac{1}{2}$ lb.), 2 poods ($72\frac{1}{2}$ lbs.) being scrap, and 0·32 cubic arshin (4·06 cubic feet) of charcoal. If scrap-iron alone be used, there are some slight differences in the operation. The output of refined iron from the furnace per week is, with scrap-iron alone, 750 poods (12 tons 1 cwt. $104\frac{1}{2}$ lbs.), and with a mixture of pig- and scrap-iron, 465 poods (9 tons 10 cwt.); and the weekly wages of the foreman 9–11 roubles, of the under-foreman $7\frac{1}{2}$–$9\frac{1}{2}$ roubles, and of the labourer $3\frac{1}{2}$–$5\frac{1}{2}$ roubles.

G. K.

The Sulphur Deposits of Southern Utah.

By A. Faber du Faur.

(Transactions of the American Institute of Mining Engineers, July 1887.)

The Cove Creek sulphur bed in Beaver County, Southern Utah, was discovered in 1869, and since that time various additional claims have been taken up. In 1883 a plant for extracting sulphur was put up, which, proving to be perfectly successful, the pro-

perty was transferred in 1885 to the company organized under the laws of Utah.

The mines are 26 miles east of Black Rock, a station on the Utah Central Railway, 204 miles south of Salt Lake City. In the vicinity is Cove Creek fort, one of the Mormon defences against the Indians. A hill about 3 miles distant from the fort, rising to a height of 1000 feet, is considered by Professor G. vom Rath, of Bonn, who has given the most detailed account of the locality, to be an extinct volcano, and is called by him Mount Dickert, after the discoverer.

The sulphur occurs mainly as an impregnation of different rocks both sedimentary and volcanic. In the Mammoth claim limestone and slate are impregnated with it to such an extent that masses up to 1 foot in diameter are found with only a few included fragments of rock. Gypsum also occurs as a product of the alternation of the limestone. At the Sulphur King the rock carrying the sulphur is a decomposed andesite basalt. The mines are situated in a small basin near the foot of Sulphur Mountains at a level of about 6000 feet above the sea; the mountains, which are composed of volcanic materials, andesite and trachyte, are about 2000 feet higher. Splinters of obsidian are scattered over the surface of the hills.

The explored extent of the sulphur bed is about 1,800 feet by 1000 feet, and the quantity of sulphur contained was estimated by Professor vom Rath, at the time when the extent developed was less than at present, to be at least 1,300,000 tons. A curved cut near the western end of the bed showed a vertical wall of yellow sulphur 34 feet high, and it also comes up to the surface over part of the basin where it is usually hidden by sand, or rather decomposed rock. The surface is wavy, giving the impression of an agitated mass slowly cooled. The sulphur, which is partly mixed with sand and gypsum, is principally yellow, but some portion is dark grey, and is known as black sulphur. The pure portions resemble the so-called "virgin rock," which is found as a product of distillation in the sulphur-flower chamber, particularly when the operation is too rapidly performed. Other products resemble the delicate crystals found on the walls of such chambers, and others again the crystals are like those found in slowly cooled masses of sulphur. Gases escape at many places in the cutting and from the prospect holes, together with saline water, and in places a high temperature is observed. The whole of these phenomena point to a solfataric action in connection with some expiring or dormant volcanic energy.

The sulphur is extracted from the ore by liquation in cast-iron cylinders, into which the ore is charged and steam admitted. The charge rests upon a cast-iron grating, supported by a steam-jacketed kettle which receives the molten sulphur. The ore is charged through a man-hole at the top, while the exhausted rock which is retained above the grating is removed by a lateral man-hole. The sulphur from the kettles is run into moulds.

The plant includes four steam liquation-cylinders, two grinding-

mills, two retorts, a chamber for making flowers of sulphur, and apparatus for making roll sulphur.

The productive capacity is 10 tons of crude sulphur per day, but up to July 1887 only 1,200 tons had been made in one year.

The greater part of the produce is ground fine and shipped in bags containing 100 lbs., the flowers of sulphur are also similarly packed. During the year ending May 1887 over 1,100 tons of ground sulphur were sold. The great obstacle to the full development of this new industry is the cost of cartage to the railway, but it is hoped that this will be diminished shortly by a new line being within a very short distance of the mine.

H. B.

On Brittleness induced in Iron by Pickling. By A. Ledebur.

(Stahl und Eisen, vol. vii., 1887, p. 682.)

This memoir records a long series of experiments upon the strength of wires of iron and moderately soft steel, which have been subjected to the action of water acidulated with sulphuric acid in order to remove scale from the surface. The fact that wire so heated becomes extremely brittle from the absorption of hydrogen, was first published by Professor Hughes, F.R.S., in 1880, in the Proceedings of the Society of Telegraph-Engineers, and subsequently in 1887 Mr. Dittmar of Aachen, called attention to the fact that this brittleness gradually disappears when the pickled wire is left at rest for some time. The Author's experiments were conducted with eight different qualities of wire whose composition was:—

No.		C.	Si.	P.	Mn.
1.	Charcoal iron wire, unannealed .	Undet.	..	0·08	..
2.	Soft ingot iron	0·06	0·08	0·16	0·18
3.	Semi-soft do.	0·27	0·15	0·11	0·49
4.	Puddled iron wire, annealed . .	Undet.	..	0·07	..
5.	,, ,, semi-soft . .	,,	..	0·20	..
6.	Patent cast-steel wire, unannealed	0·43	0·01	0·03	0·25
7.	,, ,, semi-soft .	0·51	0·01	Undet.	0·20
8.	Extra tough steel wire	0·38	0·02	0·02	0·20

The wires were treated in different ways. First, by pickling in 1 per cent. sulphuric-acid water for twenty-four hours without previous cleaning, the tests being applied after three days; secondly, by pickling in $2\frac{1}{2}$ per cent. acid for twenty-three hours after cleaning the surfaces with ether, the mechanical tests being applied immediately; thirdly, by protecting the wire from direct attack by attaching a mass of zinc to one end, when a very rapid development of hydrogen takes place on the surface of the iron, which becomes brittle without being actually attacked, as previously demonstrated by Professor Hughes, and testing at once; while in a fourth series repeating the third treatment, the samples were only tested after four days' interval. The general result of these

four series showed that although the ultimate tensile strength of the wire was not diminished, but if anything slightly increased by pickling, the ductility as measured by the ultimate extension was reduced about 15 per cent., and the flexibility as indicated by the number of bends producing fracture, by 39 per cent., or from 9·48 to 5·78 bends.

A fifth series of experiments showed that the original quality of the pickled wire was nearly restored by annealing it at a red heat in a current of carbonic oxide and nitrogen, the ultimate difference in ductility and flexibility between the black wire and that pickled and annealed being only 5·9 per cent. in extension, and 9·8 per cent. in the number of bends. Very weak acid, 1 to 200 of water, behaved similarly when the action was continued for some days, and the acid water from the Freiberg mines also had some slight effect in producing brittleness. A very decided deterioration was also produced by exposing the wires to atmospheric oxidation for about two months, their ultimate extension and bending flexibility being reduced by about one half in both. When, however, the freely exposed wires were protected from direct oxidation by coating the ends with zinc, only a very slight change took place in a fortnight.

The influence of time in restoring the flexibility of pickled wire was tested by allowing samples to rest in dry air for four weeks before testing, when the loss of flexibility, which was at first 76·3 per cent., diminished to about 17·5 per cent. This change was not, however, accompanied with a corresponding recovery in ductility, as in most instances the brittleness was, if anything, rather increased. Subsequent experiments made with bars of spring-steel of 0·65 to 0·9 per cent. carbon temper showed a loss of strength varying from 20 to 40 per cent. due to pickling when subjected to a bending test. Cast-iron was but very slightly affected by twenty-four hours' pickling in 2 per cent. acid water; but with 8 per cent. acid and nine days' exposure the transverse strength and flexibility were reduced from 11 to 19 per cent.

The Author considers that the following five propositions are established by the result of the experiments.

1. In all cases where malleable iron is exposed to influences likely to generate hydrogen upon its surface, and more particularly to the action of weak acid, a change in its mechanical properties results, the modulus of tensile strength being unaltered so long as the metal is not sensibly corroded, but the extension under stress and the capacity of resisting bending strains are notably diminished. In consequence of these changes the iron can be more easily broken, either by repeated bending or by simple bending-strains than in the original state.

2. An action similar to that of weak acid is produced by the atmosphere when iron is exposed to it in an unprotected condition.

3. Contact of the iron with zinc, which renders the former electro-negative, has a notable effect in increasing the influence of the acid on the unprotected portion of the surface, so that a

very much shorter time suffices to produce brittleness than without such contact.

4. The brittleness produced by pickling or rusting is removed by annealing, and also disappears, or is considerably diminished, by allowing the brittle metal to rest for some time in a perfectly dry place. It cannot, however, be removed by mechanical treatment in the cold.

5. Cast-iron is not sensibly, or only very slightly, affected by pickling.

Finally, the Author made some direct determination of the hydrogen contained in the brittle wire. For this purpose four samples of charcoal iron wire, weighing from 60 to 75 grams, were, after pickling, heated to redness in a current of nitrogen, the gas expelled was oxidized by cupric oxide, and the resulting water collected in anhydrous phosphoric acid. The results obtained were as follows :—

Wire of 2·5 millimetres.	Hydrogen . . .	0·0021 per cent.
,, ,,	,, . . .	0·0028 ,,
,, 3 millimetres.	,, . . .	0·0052 ,,
,, ,,	,, . . .	0·0035 ,,

Although the presence of hydrogen has thus been established in the pickled wire, it seems at first sight doubtful whether such minute quantities can be sufficient to produce the very remarkable changes in the mechanical properties demonstrated by the experiments. In considering this point, the Author suggests that the influence of a foreign substance upon iron may be determined not so much by the weight as by the number of atoms present, and, therefore, that hydrogen, whose atomic weight is only $\frac{1}{3}\frac{1}{1}$ that of phosphorus, the element which it most nearly simulates in effect, may be sufficient to produce very decided brittleness, even when present in scarcely appreciable quantity.

H. B.

On the Use of Magnesite as a Refractory Material.

By K. Sorge.

(Stahl und Eisen, vol. vii., 1887, p. 850.)

Although the value of magnesia as a material for the linings of open-hearth steel furnaces was, according to the Author, demonstrated by a comprehensive series of trials made by Wasum in 1884, it has not up to the present time been very largely adopted, in spite of its evident advantages. This is to be ascribed to the use of an inappropriate raw material. In the earlier trials the bricks were made of precipitated magnesia, which is nearly chemically pure, and practically without cohesive power, so that an addition of foreign binding matter (clay, alkalies, &c.) became necessary in order to obtain bricks of sufficient strength,

and by this means the refractory character was appreciably injured. The results obtained with magnesite from Upper Silesia and Eubœa, in Greece, were very similar, as these minerals, when calcined and exposed to the highest attainable temperature, showed no signs of fritting, so that an addition of at least as much as 15 per cent. of clay was required to make serviceable bricks. The only useful variety of the mineral that has been found is that from the Veitschthal in Styria, which is of a sparry crystalline character, and varies in composition between the following limits:

Carbonate of magnesia	90·0	to 96·0	per cent.
„ lime	0·5	„ 2·0	„
„ iron	3·0	„ 6·0	„
Silica	Max.	1·0	„
Sesquioxide of manganese . . .	„	0·5	„

The small proportion of iron present imparts the property of softening without fusion at a high temperature. The specific gravity, which in the natural mineral is about 3·0, is increased to 3·4 when burnt to the caustic condition, and to 3·6 when "dead burnt." In the latter state it is perfectly stable in the air, and may be exposed for years without taking up either water or carbonic acid, and when made into bricks only contracts about 4 per cent. upon the moulded volume. For the latter purpose, however, a small proportion of binding material is necessary, and the moulding must be effected by hydraulic pressure. The most convenient size of brick is 240 × 120 × 65 millimetres. In setting the bricks either tar or magnesia mortar may be used; the latter is made of caustic, mixed with a variable proportion of strongly burnt magnesia. This is used with as little water, and the narrowest possible joints in the brickwork. Owing to the very high temperature required to produce cohesion, it is not advantageous to attempt to make the whole thickness of the hearth out of the plastic mass, but is preferable to build it up of bricks either flat or edgewise, and to make the working surface by a covering of moulded mass from 15 to 30 millimetres thick. This is applied to the brickwork after the latter has been exposed to a bright red heat for forty-eight hours, when the finely-ground material is introduced, a shovelful at a time, and beaten down by rammers weighing from 30 to 60 kilograms. Much depends upon the manner in which this part of the work is done. When the bed is finished a layer of 2 to 3 centimetres of lime is laid upon it, and upon this the charge of iron and other materials is made.

When properly made a magnesia lining will last during the working of from five hundred to six hundred charges, and, except where accidents happened at first, the endurance has rarely fallen below three hundred charges. Many smelters consider it advantageous to take out and replace the uppermost layer of the brickwork after melting three hundred charges, in order to avoid larger and more expensive repairs at a time. The average amount of material required for making good the injury to the hearth during the working may be taken at about 20 to 25 kilo-

grams per ton of steel produced. The price of magnesite bricks in Westphalia is about £7 per ton, and that of the plastic mass £5 15*s*. At these prices the amount required for a 10-ton furnace will cost :—

	£.	*s*.
Bricks, 12 tons	84	0
Plastic mass, 3 tons	17	5
	£101	5

Assuming that the hearth is entirely renewed after three hundred charges, or a total production of 5,000 tons of ingots, the expenditure will be :—

	£.	*s*.
Lining as above	101	5
Material for repairs, 5,000 × 20 kilograms = 100 tons	575	0
	£676	5

The cost of magnesite reduced to the ton of steel produced is therefore about 2*s*. 9*d*.

The advantages due to the use of this material are said to be :—

1. The charge may be dephosphorized to the extent of 98 per cent. of its total phosphorus without difficulty.

2. Magnesite bottoms allow of the addition to the charge of 30 per cent. and upwards of iron ore, and, therefore, facilitates the use of every kind of raw material.

3. Magnesite bricks may be made of very regular shape, so that the building of the hearth in an accurate and durable form is much facilitated.

4. Magnesite may be built up in direct contrast with silica brickwork, which is not possible with any other kind of basic material.

5. The durability of a magnesia lining far exceeds that of any other basic substance, and is, therefore, less costly, as not requiring extensive repairs at short intervals.

6. Magnesite, when exposed to the action of basic slags and metallic oxides, resists corrosion better than any other known substance.

7. The absolute indifference of bricks and burnt magnesite to the action of the air makes it possible to preserve them in quantity for any time without fear of alteration.

8. The danger of using a partially altered material, and therefore one of small durability, as may happen with dolomite, is completely avoided with magnesite.

These advantages are sufficient to counterbalance the somewhat high price of magnesite products, and the Author considers that it would be to the interest of every open-hearth steelworks to make at least one experiment with them on the large scale. With 12- and 15-ton furnaces the cost per ton would be proportionately smaller than the figures given above.

H. B.

Cost of Colliery-Surveys in Westphalia. By H. Werneke.

(Mittheilungen aus dem Markscheiderwesen, 1888, p. 32.)

From information supplied by the Royal Mining Department of Westphalia, the Author states that, at the one hundred and ninety-four collieries in that district, during the years 1880, 1881, and 1882, the average annual expenditure on the preparation of mine plans, and on other mine-surveying operations, amounted to £9,323 16*s*. This sum represents an average of 8¾*d*. for every 100 tons of coal raised, or 2*s*. 1*d*. for each workman employed.

B. H. B.

An Underground Pumping-Engine at Mechalkowitz in Moravia. By R. Sauer.

(Oesterreichische Zeitschrift für Berg- und Hüttenwesen, 1887, p. 567.)

On the 19th of November, 1885, a sudden influx of water took place in the coal district belonging to the Northern Railway at Mechalkowitz, which has rendered it necessary to increase the drainage-power to the extent of about 1 ton (220 gallons) of water per minute for some time to come. The existing pumping arrangements (a direct-acting engine in each of the two working-shafts) being only sufficient to deal with about half that quantity, a new engine has been placed underground at a depth of 247 metres from the surface, which has been so designed as to be capable of doing the normal pumping work, about half a cubic metre per minute, with the highest attainable economy of steam; while, at the same time, it is susceptible, by alterations in the method and speed of working, and by increasing the size of the pump-plungers, of lifting as much as 4 tons of water per minute. The engine, which has been designed by Professor Riedler, of Aachen, is of the compound-receiver class, two horizontal engines with cylinders of 500 and 700 millimetres (20 and 27½ inches) diameter, and 700 millimetre stroke, being coupled together at 90° on the same fly-wheel shaft. Each piston-rod drives two single-acting plunger-pumps, which are placed back to back, and connected with the rod by crossheads and side-rods. For ordinary working (as a compound engine), with 45 lbs. boiler-pressure, the plungers used are 98 millimetres in diameter, but in forced work with full-pressure steam in both cylinders, they are changed for others of 150 millimetres. With these dimensions, and assuming the effective volume of the pumps at 96 per cent., the normal duty of 0·5 cubic metre (110 gallons) per minute is realized with 25 revolutions, which, by merely increasing the speed up to 100 revolutions can be augmented to 2 cubic metres lifted 250 metres per minute. The total pressure on the plungers under these

conditions does not attain 2,000 kilograms (2 tons), and therefore, with the initial boiler-pressure of four atmospheres, a very high degree of expansion may be realized.

In forced working, with the larger plungers with fresh steam in both cylinders, a mean pressure of three atmospheres in the smaller and of two atmospheres in the larger one is required, so that even in this case, twofold expansion may be realized in the latter, and threefold in the former cylinder, without requiring an undue initial pressure, the water in the rising-pipe being heated to at most 54° or 60° Fahrenheit, by the condenser discharge. The maximum pump-pressure is about 4,750 kilograms with the large plungers, and that on the steam side about 2,000 kilograms, when both pressure and vacuum are completely utilized, and these strains have been used in determining the dimensions of the moving parts. The rising-pipe, which is designed for a maximum discharge of 5 cubic metres (1,100 gallons) at a speed of 4 metres per second, is 160 millimetres (6·3 inches) in diameter. This, though small, has proved to be amply sufficient for all the requirements.

In accordance with Professor Riedler's proposition, two lines of main steam-pipes from the boilers at the surface to the pit-bottom have been adopted; one of these is made of wrought-iron tubes 89 millimetres (3½ inches) in diameter, and suffices for ordinary working up to a speed of 75 revolutions, while the other of cast-iron, of 200 millimetres (7·9 inches) bore, is held in reserve for forced working with full steam in both cylinders.

The dimensions of the steam-pipes have been calculated from the results of the experiments made at Louisenthal, Saarbrucken, the following being the most essential details:—

1. *Normal Compound Working.*—The effective pump duty for half a ton of water lifted per minute is 28½ HP. at 25 revolutions per minute, corresponding to a speed of 6 metres per second for the steam-supply, at which rate no appreciable loss of pressure is experienced in a total length of pipes of 280 metres. The steam required on the assumption of 10·5 kilograms per effective pump HP. is about 300 kilograms per hour, or 0·0313 cubic metre per second, which requires a sectional area of 0·005217 square metre, or 82 millimetres diameter, or allowing for accessory resistances, 89 millimetres, the size chosen. This has proved to satisfy the requirements of compound working at all speeds, and even for the double supply at moderate speeds. The loss by condensation, taken at 1·5 kilogram per square metre of pipe surface per hour, increases the amount of steam required by 3·2 kilograms per HP. per hour, raising the speed in the pipes to 7·7 metres per second, and requiring an augmentation of pressure of 0·09 atmosphere.

2. *Forced Working.*—This is based upon an assumed duty of 310 IHP., a steam consumption of 12 kilograms per IHP. per hour, and 12 metres speed in the supply-pipe, giving 205 millimetres as the diameter of the latter (200 being actually adopted).

The calculated loss of pressure is 0·22 atmosphere, and the total steam consumption 12·4 kilograms per indicated, or 16·12 kilograms per effective HP. If a supply-pipe of this size had been relied upon for ordinary compound working, the velocity of the steam-supply would be only 1·2 metre per second, and the loss from condensation would amount to 7·7 kilograms per effective HP. per hour, or the steam required would be increased from 10·5 to 18·2 kilograms, which figures sufficiently show the necessity of the smaller supply-pipe for ordinary use.

The steam-pipes are supported by iron girders on the shaft, and three compensation-joints are inserted in the vertical height of 234 metres. There are nine stuffing-boxes bushed with metal, and packed with asbestos rope. A fixed bearing is placed immediately above each compensation joint. The tubes are also furnished with guides at about 12 metres interval, to prevent them from bellying. Externally they are covered with a layer of the non-conducting material made by Posnansky and Strelitz, of Vienna. This is 60 millimetres thick, and is finished by a covering of tarred canvas varnished. The flanges of the tubes are also covered.

Both lines of steam-pipes terminate below in a drum of 870 millimetres diameter, and 2·3 metres high, in which the condensed water is separated from the steam before it reaches the engines. The steam-cylinders and their covers are jacketed, as is also the low-pressure slide-valve cover. The high-pressure cylinder has a Rider slide-valve which is controlled automatically by a Porter governor, which can be set for 50, 75, or 100 revolutions per minute by alteration in the driving-straps and counterweights. The low-pressure cylinder has a Mayer's expansion-slide adjustable by hand. The slide-valves are driven from the fly-wheel by a countershaft and bevel gearing, and the same shaft also moves the pump-valves, whose action is not dependent upon the exhaust of the plunger, but depends upon Riedler's patent gearing, which assures correct working at high speeds. These valves are of a simple annular form, with stalk-guides. Those on the water side are driven by a prolongation of the valve-rod passing through the top stuffing-box, while the discharge-valves are moved by oscillating-levers. Both sets are so combined that a single cam on the valve-shaft moves all four valves on the same side of the engine.

The engine, which was constructed by the Prague Engine Company, was set to work in February, 1887, and trials were made under the most varying conditions. As a compound engine, it has been driven up to 106 revolutions, and with full steam in both cylinders, and the larger plungers, up to 100 revolutions. It has also been tried with the larger plungers on one side only, the other pair being disconnected. In the latter case rather considerable variations of pressure were experienced at first, but they disappeared after a short time. From the 10th to the 28th of April, 1887, experiments were made in order to determine the

loss by condensation, actual steam-consumption, &c., the results of which are given in the following tabular statements:—

I. Condensation in the steam-pipes—engine standing.

Duration of experiment		5h.	4h. 54m.	1h. 5m.	4h. 4m.	4h. 32m.	3h. 42m.
Diameter of steam-pipe		200	200	200	200	89	89
Boiler pressure .	atmos.	4·5	2·98	4·46	4·47	4·48	3·02
Condensed water per square metre per hour	kilog.	0·930	0·778	0·830	0·910	1·020	0·900

Or an average of 0·862 kilograms per square metre for the large, and 0·960 for the small tube.

Condensation in steam-pipes—engine going.

Duration of experiment . . .	4h. 5m.	2h. 54m.	3h. 41m.
Diameter of steam-pipe . . .	200	89	89
„ plunger	150	150	90
Revolutions per minute . . .	30	35	35
Boiler pressure . . atmospheres	3·85	4·32	4·51
Condensation per square metre per hour . . kilogram	0·890	1·200	1·300

II. The measurement of the pump-discharge proved to be 95·5 per cent. of the volume described by the plungers. During the time of the experiments, however, the water was dirty, so that the valves did not close perfectly tightly, and experiments with the more perfectly adjusted valves have not yet been made.

III. In order to determine the steam consumption, experiments were made in compound working at speeds from 30 to 85 revolutions, corresponding to 37 to 178 HP., and with full steam at 30 to 65 revolutions, the trials being continued for ten hours in each instance. The results were—

A. For compound working.

Diameter of steam-pipe	89	89	89	89
„ plungers	98	98	150	98
Number of revolutions	85	33	35	35
Gross steam consumption per effective pump HP. per hour in kilograms—				
Inclusive of condensation . . .	11·7	14·2	15·6	16·31
Without „ . . .	10·8	12·15	14·7	14·05
Do. per IHP. without condensation	8·4	10·1	12·7	11·17

B. Working with full steam, and 150 millimetres plungers.

Diameter of steam-pipe	89	200	200
Number of revolutions	41	65	30
Gross steam consumption per effective pump HP. per hour in kilograms—			
Including condensation	15·1	15·1	17·01
Without „	14·34	14·15	15·0
Do. per IHP.	12·1	12·0	13·0

It has not been possible to make continuous trials at the higher speeds (80 to 100 revolutions), as the standage room in the sump is not sufficient to supply more than two or three hours' feed to

the pumps, which is too short a time for determining the steam consumption.

The calculated efficiency of the engines, working with full steam, is 86·75 per cent. from an average of three trials at 33 revolutions, and 79·5 per cent. for a single compound trial at 35 revolutions.

The average rise in temperature in the water discharged was about seven degrees above that of the mine sump.

The cost of the entire plant is given as follows (at 10 gulden per £ sterling):—

	£.	s.
Excavation of engine-room, pipe-drifts, &c. . . .	155	18
Masonry of engine-room, drifts, and engine-bed .	1,027	8
Cost of engine, including carriage and erection . .	2,237	10
Purchase, erection, and covering of pipes . . .	1,233	15
	£4,654	11

H. B.

On the Electro-Dynamic Force produced by the Motion of a Dielectric in a Homogeneous Electrical Field.

By W. C. Röntgen.

(Sitzungsberichte der Akademie der Wissenschaften, Berlin, 1888, p. 23.)

The Author considers that by the experiments described in this Paper, an electrodynamic force results from the motion of a dielectric in a homogeneous electrical field. After a preliminary theoretical dissertation as to the possibility of such an effect arising from the polarization of the particles of the dielectric, and the retardation thereby ensuing, the apparatus and physical constants thereof are described in detail. Between the two horizontal plates of a condenser was mounted a glass disk, in such manner that the latter could be rapidly rotated, and just above the upper plate was suspended a delicate astatic system of magnets, with mirror attached, for reading its deflection in the ordinary manner. With a difference of potential between the two plates sufficient to give a spark of 0·3 centimetre (0·12 inch) in air, and the plate rotated 100 revolutions per second, a deflection was obtained of between 2 and 3 divisions (0·1 inch) on a scale distant 229 centimetres (7·5 feet) from the mirror. To prove that this effect was not due to any charge communicated to the rotating-plate itself, a separate experiment was tried with the lower plate of the condenser cut in half and oppositely electrified, when the deflection remained practically the same as before. The Author hopes to be able to obtain more decided and quantitative results, and points out the possibility—assuming that the same medium (the ether) serves for the transmission of the luminous and the electrical energy—of determining the mooted question as to the

existence of a difference in velocity between the bodies on the earth's surface and the ether surrounding them, the Author's own observations by this method being, however, absolutely negative in their results. The connection between this subject and other electrical questions is also pointed out, but the extreme difficulty of their experimental execution renders these hypotheses of no practical importance.

F. J.

The Electromotive Force of Bichromate Batteries.

By André Reynier.

(L'Électricien, 1887, p. 772.)

The introduction within the last three years of commercial bichromate of soda as a source of chromic acid has led to the almost general adoption of this salt for batteries of the Poggendorff type. Its chemical equivalent is less than that of bichromate of potash; it is richer in chromic acid, has a greater solubility, and is about 25 per cent. cheaper.

The Author has measured the electromotive force of a number of single-fluid and two-fluid cells. One group of each kind was made up with various proportions of bichromate of potash and sulphuric acid, and the other two groups with bichromate of soda and acid.

Data relating to the different combinations and to the electromotive force of each cell are embodied in a Table. From the results obtained the Author deduces the following conclusions :—

I. In all cases the electromotive force is greater with amalgamated than with ordinary zinc.

II. Retort carbon gives better results than manufactured plates.

III. The electromotive force varies inversely as the temperature, the effect being very marked for differences of 5° Centigrade and upwards.

IV. The composition of the liquids is the most important point in bichromate batteries. The Table shows that with chromic solutions of similar proportions, the two-fluid cells have a higher electromotive force than the single-fluid ones. When the density of the solution is about the same in each type, the electromotive force of the soda and potash batteries is practically the same, and it increases, in general, directly as the density.

J. J. W.

Bichromate Batteries. By André Reynier.

(L'Électricien, 1888, p. 37.)

The Author's previous Paper[1] had reference to batteries, the activity of which is maintained by the double reaction of sulphuric acid on zinc and bichromate of potash, or soda. A battery of a similar type, but worked with hydrochloric instead of sulphuric acid, is also used for various purposes, but its chemical constitution is so different to that of the true Poggendorff cell that it cannot, in all cases, be substituted for the latter. A comparison of the respective formulas shows that the combination with hydrochloric acid yields by-products in the form of chlorides which are more soluble than the corresponding sulphates, so that, with the same number of equivalents of acid, a current of equal strength from each battery would be maintained for a longer time by the one containing hydrochloric acid. This advantage is, however, only apparent, as the following data have to be considered:—

1. The weights of the solutions of hydrochloric and sulphuric acid are as 1 to 0·47.
2. The corresponding volumes as 1 to 0·30.
3. The prices as 1 to 0·58.

Hence the use of hydrochloric acid (the dearer of the two) to produce a given number of coulombs would be disadvantageous, for more than twice the weight of sulphuric acid and three times its volume would be needed.

J. J. W.

The Desmazures Accumulators. By Emile Reynier.

(L'Électricien, 1887, p. 657.)

Messrs. Lalande and Chaperon have tried to make their well-known primary battery regenerative by means of electrolysis, but the results have not been of value in the commercial sense. Success in this direction has, however, been attained by Mr. Desmazures, with accumulators of the following type:—

The negative plates consist of tinned sheet-iron; the positive are of porous copper, obtained by submitting the pulverulent metal to a pressure of 600 to 1,200 atmospheres. The liquid is a solution of zinc in sodium or potassium hydrate, with the addition of sodium chlorate. The containing vessel, also of tinned iron plate, is entirely closed in, and the negative electrodes, which are joined to it, rest on the bottom. The particles of electrolysed zinc that get detached from their support fall to the lower part of the receptacle when the battery is discharged, and re-combine

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[1] *Ante*, p. 97.

with the solution. The oxides of copper are not completely insoluble in the caustic hydrates, and to prevent their dispersion in the electrolyte and reduction on the zinc, the positive electrodes are enclosed in separators of parchmentised paper, held in position by small glass rods, which serve as insulating supports. The undermentioned data refer to a battery of pattern No. 4.

Outer dimensions	12 ins. long, 3½ ins. wide, 15¾ ins. high.
Total weight of the five positive and six negative plates	13¼ lbs.
„ „ entire accumulator	44 „
Storage-capacity	372 ampere-hours.
Duration of charge	2 hrs. 40 mins.
„ „ discharge	10 hrs. 15 mins.
Rate of charge	18 amperes.
„ discharge	36 „
Electromotive force on open circuit	1 volt.
Available potential	0·85 volt.
Electrical work at discharge	22 foot-pounds per second.
Total electrical energy given off at discharge	0·41 horse-power-hour.
Total weight of battery per horse-power hour	99·6 lbs.
„ „ „ electrical horse-power	1080 lbs.

In some recent experiments at Havre the results, as regards weight, were more favourable. A complete battery of one hundred and thirty-two accumulators, weighing complete about 2 tons, was used to propel a torpedo boat of 5 tons weight. During five hours the current from this battery was 87 to 89 amperes, at a potential of 100 to 104 volts, or a mean of 12 HP., equivalent to an electrical energy of 60 HP. hours, whence—

Total weight of battery per horse-power-hour	= 72⅔ lbs.
„ „ „ electrical horse-power (746 watts)	= 367½ „

There is nothing unusual in the latter value, but in respect of the ratio of weight to the horse-power-hour, the Desmazures accumulator is superior to any of the Planté types. The coefficient of restitution is very high, as the electrolysis of the alkaline zincates is effected without evolution of gas, the zinc being deposited in a compact and adherent form. The lasting quality of the negative electrodes is no doubt as great as in other secondary batteries; that of the positive plates is more uncertain, and the paper separators will soon perish in a caustic alkali.

The first cost of the two types of accumulators depends principally on the value of the original substances used for each. Copper and potash are much dearer than lead and sulphuric acid, and if the ordinary price of these articles be applied to the theoretical weights given by the Author in his comparison of a Planté cell with one of Lalande and Chaperon's, it is found that, with an equal consumption, the materials for the caustic hydrate combination cost four times more than those required for the Planté accumulator.

J. J. W.

The Electrical Conductivity of Amalgams.

By Carl Ludwig Weber.

(Centralblatt für Elektrotechnik, 1887, p. 716.)

The researches of A. Mathiessen and Vogt and W. Siemens on the conductivity of metals and amalgams show what abnormal results have been obtained with the latter, but do not make clear in what degree the conductivity of an amalgam is dependent on the percentage of its components. As regards the temperature coefficient, the same law applies to solid quicksilver in the pure state as to the other metals, so the Author chose a different method to that which had been previously adopted in testing the resistance of its alloys, and carried out his experiments at high temperatures. With this mode of working, each amalgam was tested while in a state of complete fluidity, whereas at an ordinary temperature poor amalgams are fluid and rich ones solid, whilst many are in neither one nor the other of these conditions.

A heat above the melting point of the less fusible constituent was fixed upon, but could only be completely attained in the case of the combinations with tin and bismuth. When the mercury was combined with metals having higher melting points, it was difficult to keep such high temperatures constant, and the volatilization of the quicksilver proved troublesome.

The alloys were put in U-shaped glass tubes with enlarged ends, and the resistance measured by means of Thomson's arrangement of the electrical balance. The tubes were maintained at the necessary temperature by suspending them in a bath of paraffin, the heat of which was kept constant by a thermostat filled with air. Special attention was given to the preparation and mixing of the alloys, and as amalgams have a great tendency to separate into two constituents of different proportions, each end of the U-tubes was closed with a cork through which passed, in addition to a rheophore of amalgamated iron wire, a small glass tube, the outer end of which terminated in an india-rubber tube. By pressing the latter, the fluid alloy could be kept in motion until the resistance measurements became fairly concordant, thereby indicating a homogeneousness of the mixture. The mean of six readings was then taken as the true one. Tests were made of amalgams of tin, bismuth, lead, and cadmium. From the tabulated results and curves of specific resistance and conductivity given in the Paper, the Author concludes that, as regards each of these fluid amalgams, the conductivity is not equal to the mean of the conductivity of its constituents, for an equivalence would require the curves to approximate closer to a straight line, as in the experiments of Mathiessen[1] with alloys of lead, tin, and cadmium in the solid state.

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[1] Mathiessen, Pogg. Ann. 110 (1860). p. 190, Plate VII, Fig. 3.

The resistance of each amalgam decreases rapidly so long as the percentage addition to the mercury of the other metal is small; when the constituents are in a certain proportion, the rate of decrease is slower. The resistance decrement of the tin and cadmium combinations is at this stage proportionate to the quantity per cent. of the added metal, so that the resistance of the amalgam becomes little by little almost the same as that of the tin or cadmium.

In the case of the amalgams of bismuth and lead, the initial decrease of resistance rapidly reaches a limit, and an increase then takes place, but before the resistance becomes that of pure fluid bismuth a maximum is again reached. The latter is not equal to the above-mentioned limit of decrease, but is nevertheless quite apparent. As regards the lead amalgams, the observations could not be carried far enough to prove the existence of a maximum between the percentage additions of 70 and 100; but the course of the curve, as far as it extends, indicates that it would be reached. Minima and maxima were obtained by Mathiessen in his experiments with solid alloys of gold with tin, and lead; but in those researches there is no analogue to the phenomenon observed by the Author in his tests of the bismuth and lead amalgams, viz., that a large number of them have a higher resistance than that of each of their constituents.

J. J. W.

On the Employment of Electrodynamometers for Measuring Alternating Currents.

By G. Maneuvrier and P. Ledeboer.

(Comptes rendus de l'Académie des Sciences, Paris, vol. cvi. 1888, p. 352.)

The investigation, both theoretical and experimental, into the magnitude of the error introduced in the measurement of periodically varying currents by the self-induction of the apparatus employed, shows that an electrodynamometer of the ordinary construction can be relied on, as giving values within 1 per cent. of the truth. A Siemens electrodynamometer with the stationary and movable coils in series, and a Carpentier with these coils parallel, gave the following results for what is termed the "factor of perturbation," when the times of a whole phase in the alternations of the currents were 0·03 and 0·01 second respectively, viz., for the Siemens instruments 1·0003 and 1·0005, and for the Carpentier 1·0010 and 1·0077. These results are true only for the currents which follow the sine function, as in the case of a machine the moving coils of which have no iron cores; if iron be present, experiment alone could be relied on; but the results were similar, and show that an electrodynamometer placed in the

main circuit of an alternate-current machine, introduces a perturbation, which is a function of the time of a complete phase, and is considerably greater for one that has its coils parallel, than for one with them in series. But, within the limits of speed employed, 500 to 1,500 turns per minute, the error in either form of instrument will not exceed 1 per cent.; and if the coefficient of self-induction be decreased in the same ratio as the time of a complete phase of the current, the measurements will be made with the same degree of approximation; as further, the variations in speed of the machine usually exceed the limit of error given above, it seems illusory to demand a higher degree of precision in the instruments for practical use.

F. J.

The Measurement of the Insulation of Leading-Wires.

By R. V. Picou.

(L'Électricien, 1887, p. 726.)

By the method of testing described in the Paper, the insulation resistance of a sample of treble-cotton-covered wire, placed on the surface of a good conductor and subjected to a pressure of 23·4 kilograms per lineal metre was found to be 11 megohms per metre. Adopting this latter figure as a standard, a coefficient can be derived therefrom, which is useful in determining if the current leakage of a group of wires connecting incandescence lamps exceeds a certain prescribed limit.

The apparatus used by the Author consisted of two plates of metal in circuit with a suitable galvanometer and coils. A piece of covered wire of known length, bent into a zigzag, was laid between the plates, and pressure applied to the upper one by means of weights.

In practice, the leading-wires of an installation are usually fixed to a supporting surface against which they are pressed with more or less force. Any device for the electrical testing of these wires should therefore reproduce as nearly as possible the surface-contacts thus formed. The ordinary telegraphic system of measuring the insulation is inapplicable, because the water in which the wire would have to be immersed penetrates to the conductor through such protective coverings as cotton and silk. The Author's arrangement has been devised for wires of this type only. Some curves are given in the Paper, the insulation being represented as a function of the pressure.

J. J. W.

The Resistance of the Electric Arc and Dynamo Armature.

By Dr. K. Feussner.

(Centralblatt für Elektrotechnik, 1888, p. 3.)

In the measurement of the resistance of an electric arc, either direct from the current-strength and potential, or by means of special arrangements of the Wheatstone bridge, the figures obtained are not the same in each case. The difference in the results has been attributed to a counter-electromotive force in the arc. A similar plan of bridge-testing has been applied to measure the resistance of the rotating armature of a dynamo, and from the tests the conclusion has been drawn that with increase of speed the resistance becomes much greater.

The Author's Paper has reference to the methods employed by V. v. Lang, L. Arons, and O. Frölich, and his analysis is intended to show that these investigators did not measure the entire resistance of the arc, but only a certain fraction thereof, and that the results have not demonstrated the existence of any counter-electromotive force. The assumed increase of resistance in the armature is attributable to the mode of measurement employed.

By the bridge method the galvanometer branch is arranged either in such wise as makes the current i_5 in this branch nil, or so that the difference of the current Δi_5 for two different values of e_6 is nil. In the first case E_1, E_2, E_3, E_4 and E_5 are all taken to be nil; then

$$i_1 - i_2 = i_3 - i_4 = 0,$$

$$i_4 w_4 - i_1 w_1 = i_2 w_2 - i_3 w_3 = 0, \quad \text{whence } w_1 w_3 = w_2 w_4.$$

In the second arrangement, however, the electromotive forces E are not assumed to be nil but only independent of i_1, that is, $\frac{\Delta E}{\Delta i} = 0$; it follows, therefore, that the resistances w must be likewise taken as independent of i, then; as in the first case—

$$\Delta i_1 - \Delta i_2 = \Delta i_3 - \Delta i_4 = -\Delta i_5 = 0,$$

$$\Delta i_4 w_4 - \Delta i_1 w_1 = \Delta i_2 w_2 - \Delta i_3 w_3 = 0,$$

whence

$$w_1 w_3 = w_2 w_4.$$

In the methods adopted by the above-named scientists the ratio $\frac{\Delta e}{\Delta i}$ is measured, and this gives the actual resistance of the arc, only under the condition that the electromotive forces E and resistances w are independent of the current-strength. The following considerations show that this condition was not fulfilled. In the measurement of the armature the current in the latter magnetized the iron in its vicinity, thereby inducing in the wire

on the armature an electromotive force approximately proportional to the speed. This force may be expressed by $E = vf(J\ A)$, where v is the speed, J the armature current, and A the distance of the surrounding iron. According to Frölich, the influence of the measuring current ΔJ does not affect the result, because it is weak in comparison with J. It has, however, been shown that $\frac{\Delta E}{\Delta J}$ has to be taken into account, as it is not nil but approximates $v\frac{df(J.A)}{dJ}$, which has a determinate limiting value, and is independent of ΔJ.

The resistance of the arc may be regarded simply as a function of the current-strength, because it is the current itself which develops and maintains the conducting power of the medium between the carbons. The nature of this function has not yet been determined, but it may be expressed empirically by

$$W = w_0 + \frac{J_1}{J} w_1,$$

where W is the required resistance, J the current-strength in the arc, J_1 the unit of current, w_0 an element of the total resistance independent of changes in the strength of current, and w_1 its complement to W with the unit of current.

The Author states that this equation must not be regarded as expressing a law, even when it accords fairly with experimental observations. The formula was deduced from the following data: The potential of an arc (whether maintained with a current of 3 amperes, or a much stronger one) keeps, with tolerable constancy, between 45 to 55 volts. The heat produced is, therefore, nearly proportional to the current; when the strength of the latter is increased, the radiating surface and cross section of the arc become greater, and, in combination with rise of temperature, cause the conducting power to augment. As most of the increase of radiation is due to the enlargement of surface, the addition to the conductivity will not be much less than the increment of current-strength, hence the greater part of the resistance can be set down as inversely proportional to the current, or $\frac{J_1}{J} w_1$ in the formula. If the resistance were represented by this member alone, the current would, with a small increase of potential at the electrodes, be infinite, and, with a slight decrease, nil. Observation shows, however, that with such small differences the changes of current-strength, although greater than those of the potential, have limiting values. Hence the positive member w_0, which is independent of the strength of current, is added to the expression. The counter-electrical force which the current generates in the arc, as in all other conductors, is then

$$-E = J.W = J w_0 + J_1 w_1.$$

It follows, therefore, that in any method of measurement, where $\frac{\Delta E}{\Delta J}$ is determined, the second member is eliminated, and the result corresponds with the quantity w_0 only, that is, the portion of the resistance which is independent of the changes of current.

J. J. W.

Guard-Ring Electrometer for Continuous Readings.

By G. Jaumann.

(Centralblatt für Elektrotechnik, 1887, p. 766.)

The central aperture of the guard-ring above the attracting-plate is nearly filled by a brass disk (termed by the Author "collector") about 8 centimetres in diameter. This disk, which is 7 millimetres thick, is joined in the centre to a short piece of metal tube terminated at the top by a small circular platform for carrying the weights used in the calibration of the instrument. The upper part of the tube is slotted at opposite points of its diameter to receive a bar-magnet, the directive force of which is nearly equal to that of the suspension; a portion of the lower part is cut away to form a chamber for the indicating mirror.

The disk, or collector, is bored at equidistant points in a circle of one centimetre radius with three fine holes for the suspending wires or threads. The torsion-head, to which the upper ends of the wires are attached, consists of a brass cap movable about a vertical axis. Three clamp-screws serve to fix the cap in any given position, and it is perforated with three holes corresponding to those in the disk beneath. When the wires are drawn through the upper holes, each end is fixed to an adjusting-screw, which is mounted horizontally in a light frame that can be raised or lowered by means of a set-screw. The trifilar suspension can, therefore, be so adjusted as to maintain perfect horizontality of the collector. A telescope is employed for observing the readings.

The attracting-plate, guard-ring and collector, with their supports, are enclosed in a square wooden protecting-case, having a central tube of the same material to cover the suspending-wires. The torsion-head is fitted on the top of the tube. The outer case is covered with tinfoil.

The Author recommends a trifilar balance of similar construction for continuous weighings. The collector is then removed, and the object to be weighed is inserted in its place.

J. J. W.

An Apparatus for Mechanically and Automatically Registering Telegraphic and Optical Signals. By E. Ducretet.

(Comptes rendus de l'Académie des Sciences, Paris, vol. cv. 1887, p. 664.)

Apparatus destined for transmitting optical signals, generally comprise, enclosed in a case, an object-glass in the principal focus of which is the source of light, a manipulator, and a receiving telescope. A little screen, worked by the manipulator, intercepts the rays of the luminous source; they are thrown and directed into space when the screen is removed by the action of the manipulator. These rays are received by the receiving-telescope; the conventional Morse signals are transmitted according to the long or short duration of the luminous rays. At the termination of the correspondence a bolt fixes the manipulator and screen.

This apparatus offers great advantages by its simplicity, but has the inconvenience of leaving no material automatic trace of dispatches transmitted or received.

The Author's apparatus renders both the emission and inscription of the optical signals permanent, by automatically recording them on a slip of paper. This is effected by means of a system of levers and wheelwork which moves the paper a greater or longer distance, according to the movement of the screen. The Paper contains illustrations of the apparatus.

E. F. B.

The Application of Electricity to the Counting of Votes in Deliberative Assemblies. By P. Le Goaziou.

(La Lumière Électrique, vol. xxvi., 1887, p. 178.)

The Author describes an apparently simple and practicable apparatus for the automatic counting and registration of votes, applicable in its most developed form to any assembly in which each member has a particular seat appropriated to his own use. The apparatus consists essentially of three portions—(1) the switch in each member's desk, with three contacts for voting "Aye," "No," and "Neutral" respectively; (2) the central collector; and (3) the three enumerators, for counting the three classes of votes separately and publicly.

The collector consists of a large insulating disk, with a series of metal contact-segments, arranged radially in three concentric circles. The number of radii is the same as the number of members, and the segments in the three circles are connected in order with the contact-pieces of the switches, those of the innermost circle with the "Aye," those of the next circle with the "Neutral," and those of the outer circle with the "No" contacts. A radial arm bears three brushes, insulated from one another, and passing

over the several circles, and these brushes again are connected with insulated rings on the axis, upon which bear three secondary brushes communicating with the enumerators. The axis of the collector is driven by clock-work, and the whole system is served by a single battery, one pole of which communicates by short branches from a single primary conductor with the centres of all the switches, while the other pole is connected with the enumerators, which are worked by the make-and-break of the current in an electro-magnet.

To illustrate the mode of working, let it be supposed that any member votes "Aye." By adjusting his switch to the proper contact he makes connection between the battery and the inner contact-piece on his radius of the collector. Thus, when the arm travels round over this radius, the inner brush, with its attached ring on the axis and the corresponding secondary brush, complete the circuit, through the "Aye" enumerator, back to the battery. This enumerator is set in motion, and an "Aye" vote is recorded.

In cases where a scrutiny may be demanded, an automatic recorder is thrown into gear by a triple switch. This consists of a roll of paper, wrapped round a drum, which is made to revolve by clockwork at a rate corresponding to that of the collector. The paper is marked with all the members' names in a vertical column, in the same order as their radii in the collector, and opposite to the column of names are three parallel columns for recording the several classes of votes. These pass under three styles, worked by electro-magnets, and inserted by the switch in the circuits between the battery and the three enumerators.

The Author points out how the number of conductors may be reduced by a slight complication in the construction of the switches, &c.

W. J. I.

New Experiments on the Electric Arc-Light. By Dr. Lecher.

(Repertorium der Physik, 1887, p. 795.)

The difference of potential between the electrodes in an arc-light has been attributed partly or wholly to the following causes: (1) a counter-electromotive force or polarization, (2) a resistance of transition due to the change of conduction from one form to another, (3) non-continuous discharge, and (4), suggested by the Author, expansion of the current's path in the space between the electrodes. The experiments here described give no support to the first supposition, but rather confirm the third.

The observations on the counter-electromotive force, made by short-circuiting the machine while the arc was burning, and noting the absence of any reverse deflection, thereby produced on a galvanometer in the main circuit, the needle of which was mechanically kept at zero and prevented from deflecting but in

that one direction, cannot be considered as a complete refutation of (1), unless the extinguished arc increases gradually in resistance; a fact which seems, however, to be shown by an experiment with a Rhumkorff coil, where an electric arc occupied that portion of the circuit where the make-and-break is usually situated, no spark being observed in the secondary circuit when the arc was allowed to burn out, but only when the carbons were rapidly separated.

The difference of potential is without doubt a function of the temperatures of the electrodes, and from this circumstance arises the difference observed when metallic electrodes are employed; thus taking the usual formula for the potential difference of the electrodes as made up of the two quantities $a + bl$, the following values in volts were obtained:—

Carbon electrodes horizontal, uncooled . .	$33{\cdot}0 + 4{\cdot}5\,l$
,, ,, vertical ,, . .	$35{\cdot}5 + 5{\cdot}7\,l$
,, ,, horizontal, cooled . . .	$25{\cdot}0 + 5{\cdot}0\,l$
Platinum electrodes	$28{\cdot}0 + 4{\cdot}1\,l$
Iron ,, ...	$20{\cdot}0 + 5{\cdot}0\,l$
Silver and copper electrodes, approximately .	$8{\cdot}0 + 6{\cdot}0\,l$

As regards the interior of the arc, the potential of a separate rod or feeler in contact with a negative carbon-electrode gave the full value of 46 volts, whereas, with the rod anywhere along the arc, the potential was almost constant at 36 volts, the positive electrode being at zero potential. This one-sided effect was not observed with any of the metallic electrodes, the potential of the interior of the arc in this case being a mean between that of the two electrodes.

The difficulty in showing whether the current is continuous or not, the Author ascribes to the extreme rapidity of the discharges between the electrodes, the variation in the current being generally swamped by the self-induction of the apparatus usually employed for the detection of such variation. Some very interesting effects were observed when a condenser and a fine horizontally-stretched brass wire—a mirror being suitably attached to the latter to show its expansion under heat—were electrically connected parallel to the electrodes, acting thus on the lines of a Cardew volt-meter possessing no coefficient of self-induction. Silver and copper electrodes gave no deflection, and likewise the silent arc between carbon electrodes, whereas the hissing arc gave a considerable deflection, which, however, completely vanished if a Ruhmkorff coil was introduced into the circuit of this apparatus.

With iron and platinum electrodes this same effect was much more marked, and it was found impossible to maintain a short arc unless the condenser was disconnected or an induction-coil introduced into its circuit. Further experiments showed that the positive electrode plays the chief part in these special effects in the case of carbon, but the negative electrode in the case of platinum and iron.

The Author summarises his positive results as follows:—

1. A counter-electromotive force by direct observation of a return-current is not yet proved.
2. The difference in potential between the electrodes is dependent on their temperature.
3. In the case of iron or platinum electrodes the discharge is non-continuous.

F. J.

The Electric Lighting of Ems. By — Imhoff.

(Centralblatt für Elektrotechnik, 1887, p. 802.)

The plant used in this installation comprises a tubular boiler of six atmospheres, with Langen's step-grate and smoke-consumer; two high-pressure engines, each of 70 HP. actual, and three shunt-wound dynamos, each giving 80 amperes and 230 volts at 600 revolutions per minute.

The dynamos are connected in parallel, and the glow-lamps are arranged on seven different branch circuits. The loss of potential in the leading wires amounts to 15 per cent. Had the lamps been on a single circuit only, the potential at the one nearest the engine-house would have been 30 volts higher than at the most distant lamp, provided all the lights were in use at the same time. The insertion of lamps varying, according to their position in the circuit, from 230 to 200 volts, would not have answered so well as the seven-circuit system. A safety-fuze, switch, and current-indicator are inserted in the main wire from the positive pole of each dynamo, and between these wires and the external circuits is a series of automatic current-regulators. The return wires are led to a commutator, each being fitted with a safety-fuze, and then connected to a separate switch in circuit with the negative poles of the dynamos, so that any circuit can be cut out at pleasure.

The current-regulator comprises a small relay, the armature of which is maintained between two contacts so long as the potential remains at the proper working-limit; a series of resistances connected to terminal bars, and arranged beneath an endless screw, which is supported at each end by a bearing that serves also as a spring-contact. The screw carries a slider, the motion of which along the surface of the bars increases or diminishes the resistance of the circuit. On one end of the screw are two pulleys, between which is a disk of iron forming the armature of two separate electro-magnets, so arranged that the lower half of the disk is between one pole of each magnet. The branch circuit in which each regulator is placed is so disposed that an undue rise or fall of potential moves the armature of the relay against one or other of the two contacts, and thereby brings into action one of the electro-magnets; the disk is attracted either to the right or left, and one of the two pulleys, which are kept in motion in contrary directions by means of bands from the shaft, gears with the disk,

and causes it to rotate as well as the endless screw. By this means the slider is actuated until it buts against one of the bearings; directly this takes place the regulating-circuit is interrupted. The pulleys of one regulator only are driven direct as described above; the other regulators being worked from this by means of an intermediate toothed-wheel gearing.

The number of glow-lamps is 883, which are divided amongst forty renters; seven arc-lamps, each of 500 candle-power, are likewise worked from the same machines. The Paper contains particulars of the length of each circuit, cross section of the leading wires, and cost to each renter for the light, according to the type of lamp used.

J. J. W.

Leduc's Magnetometers. By K. Feussner.

(Centralblatt für Elektrotechnik, p. 550.)

These instruments have been devised for testing the strength of any magnetic field. One of them embodies the principle of Lippmann's well-known mercurial galvanometer, and consists of a small rectangular glass chamber 1 centimetre (0·39 inch) in height, and the same in length, but only about $\frac{4}{100}$ centimetre wide. In each side of this chamber is a conical hole, in which is fitted the lower end of a bent glass tube, enlarged just above the bend to a cylindrical reservoir, terminating at its upper part in an open glass tube. The whole arrangement forms a mercury manometer (the left-hand branch being longer than the other, and graduated in millimetres), which is fixed to a plate of ebonite of suitable shape. Two electrodes of platinum foil, one at the top and the other at the bottom of the small chamber, are so arranged that a current can pass vertically through the thin layer of mercury. When the apparatus is held in the field to be tested, so that the ebonite plate stands perpendicularly to the lines of force, and a current is sent through the rectangular chamber, the mercury rises or falls in the left-hand tube. The strength of the field (M) is then obtained from the formula—

$$M = \frac{1}{J} g \cdot \delta \cdot \epsilon \cdot h,$$

where g is the force of gravity, ϵ width of the chamber, and h height of the mercury in the graduated tube; δ is a number by which h must be multiplied, to obtain the difference of hydrostatic pressure. As h can be read off to $\frac{1}{2}$ millimetre, M can be measured to within 5 C. G. S. units.

The other magnetometer is based on that property of bismuth by which its electrical resistance is increased when the metal is in a magnetic field. This increase is greatest when the bismuth

is perpendicular to the lines of force, and a minimum when parallel therewith. The hyperbolic equation—

$$z^2 + \beta z - a\,\mathrm{M}^2 = 0$$

gives the increment z in a bismuth wire of unit resistance in the vertical position, whence—

$$\mathrm{M} = \frac{1}{\sqrt{a}}\sqrt{z\,(z+\beta)}.$$

When z is expressed in thousandths, the coefficient a remains between 27 and 22, and β between 244 and 310.

J. J. W.

On the Influence of Temperature on the Magnetization of Iron.

By P. LEDEBOER.

(Comptes rendus de l'Académie des Sciences, Paris, vol. cvi. 1888, p. 129.)

The Author has previously shown that the extra current induced by an iron bar is proportional to its magnetic moment or magnetic permeability. The method, therefore, adopted to determine the change of permeability with temperature was based on this demonstration, the coil surrounding the bar forming one arm of an electrical bridge, its own self-induction being counter-balanced by a similar coil introduced in the opposite arm; and thus the current due to the magnetization of the iron alone was observed.

The bar was heated to any given temperature by being enclosed in a double inductionless spiral of platinum wire, through which a current was passed of sufficient intensity to raise it to the required temperature, such temperature being determined by a thermo-electric couple of platinum and rhodio-platinum, the indications of which were calibrated as proposed by Mr. Châtelier by comparison with the following fixed melting points:—340° Centigrade chloride of silver, 665° Centigrade selenium, and 1015° Centigrade bisulphate of potash. The advantages resulting from this method of heating are uniformity of temperature, absence of any injurious gases, and facility of regulation to any temperature whatever.

The results obtained on a bar of special soft iron when subjected to magnetizing powers of 35, 100, and 200 C.G.S. units, show that up to 680° Centigrade the magnetic properties are the same as when cold, and the decrease in magnetic permeability is then extremely rapid, so that at 770° Centigrade all trace of magnetism has completely disappeared, and that on re-cooling the magnetic properties reappear as before.

The change in the molecular state of iron at this temperature agrees with recent observations in its specific heat at high

temperatures, Mr. Pionchon[1] having demonstrated that a sudden change in the value of this latter quantity occurs between the temperatures of 660° and 720° Centigrade.

F. J.

The Influence of Light on Electrical Discharge.

By E. Wiedemann and H. Ebert.

(Annalen der Physik und Chemie, 1888, p. 241.)

The Authors have investigated the nature of the action of light on the electrical discharge, a property published recently by Herz. The effect is strongest when the ultra-violet rays are employed, the red and ultra-red having no effect whatever. If the ultra-violet rays are thrown on to the pole of a spark-micrometer from which the negative discharge proceeds, the spark will then traverse a greater distance, while its path will be more regular and defined. Illumination of the positive pole has much less influence in altering the discharge; while, if only of the air-space between the points, no effect at all results. These different effects were observed most successfully by using a telephone with its coil wound with specially well insulated wire, the rapidity and the regularity of the discharge being then revealed by the pitch and purity of the note emitted. With rarefied air, the effect at first increased until a maximum was reached at between 30 and 40 centimetres (12 and 16 inches) pressure, and then decreased until, at a pressure of about 100 millimetres (4 inches), no action was discernible. Similar effects were also produced if certain gases were used in place of air between the points of discharge.

The explanation of this property of light is ascribed to a species of reinforcement of synchronous vibrations, the discharging point being considered not as a conductor, but as a wave-surface, and the electrical and luminous vibrations of the ether thence propagated being of a similar order of magnitude.

F. J.

Unipolar Induction. By Dr. E. Hoppe.

(Electrotechnische Zeitschrift, 1887, p. 417.)

In a Paper of Edlund's on this subject,[2] it is stated that it is incorrect to regard a unipolar induction current as due to the rotation of a magnet *per se*, even when the latter forms part of the

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[1] Comptes rendus, vol. civ. 1887, p. 135; also Minutes of Proceedings, Inst. C.E. vol. xc. p. 569.

[2] Wiedemann's Annalen, vol. 2, 1877, p. 352.

circuit, and that the current is really caused by the revolving of a portion of the circuit. The results of some experiments by Exner and Czermak[1] controvert this view, and Schwedoff's mathematical analysis shows that, according to Edlund's theory, the electromotive force of every closed circuit rotating about an axis is nil. It follows, therefore, that the axial revolution of any body (whether homogeneous or heterogeneous, magnetic or neutral, conducting or non-conducting) can never give rise to a current in any curve representing a closed circuit, and this deduction applies also to the earth. Edlund, in a previous article,[2] avers that the induction at the axis of rotation is greater than that manifested in a direction perpendicular thereto, and bases this opinion on the results of Plücker's experiment on the induction of a magnet rotating around a portion of a circuit. If this experiment be applied to the case of the earth, and the assumption be made that magnetic masses revolve round its axis, then each such mass would give rise to an induction towards the pole stronger than that developed in a direction at right angles to the axis, hence positive electricity would be collected at the pole and negative at the equator.

The results obtained by the Author with the apparatus herein described prove the untenableness of Edlund's views, as well as those of Plücker. As regards the electromotive force of induction, the parts of the circuit which rotate exercise no action whatever, and must be regarded simply as a portion of a closed circuit having a certain resistance.

The apparatus consisted of a magnet made of a tube of forged steel 6 inches long, the outer diameter being 2 inches, and thickness of metal 0·4 inch. In the middle of the cylinder there are four holes, one pair being at right-angles to the other. A brass arm with a thread on the inner end for screwing into a central boss passes through an ebonite ferrule in each hole, so as to be insulated from the magnet. To the ends of the four radial arms projecting outside the cylinder is fastened a brass ring, the outer diameter of which is 4·7 inches, and the central boss inside the cylinder carries a brass rod. The upper end of this rod projects a little above the top of the cylinder which is fitted with an ebonite disk having a central hole for the reception of the rod, which is thus kept in the axis of rotation. By using shorter radial arms a smaller ring of 2·8 inches is available. Let the apparatus with the large ring be designated No. I, and the arrangement with the other ring No. II; *b* has reference to the top of the axial rod, *c* to the central boss, and *d* to the outside of the ring.

When the apparatus is mounted on a whirling table and set in motion, contact being maintained at *b* and *d* with the coils of a sensitive galvanometer by means of brushes, a current is set up, which passes from *b* through the galvanometer to *d*, if the direction

[1] Wiener Sitzungsberichte, July 1886, p. 358.
[2] Wiedemann's Annalen, vol. 29, 1866, p. 420.

of rotation is reverse to that of clock-hands, and from *d* to *b* when the apparatus is revolved the other way. The Author fitted a copper cylinder (1 and 2) to each ring of apparatus Nos. I and II. If the seat of the electromotive force be in the rotating portion of the circuit, a current will flow upwards in the copper cylinder but when one brush is in connection with *b*, and the other put in contact with various parts of 1 or 2, the results show that the addition of a copper cylinder has no effect. As half the length of the magnet is 2·95 inches (75 millimetres), and *b* projects about 0·39 inch above its upper edge, the electromotive force at a point 3·42 inches from the bottom edge of the copper cylinder, should, according to Edlund's theory, act in the opposite or minus direction; but in the Author's experiments, the small force detected at this point was in the same direction as at other parts of the cylinder and of positive sign. These researches confirm the theory of induction, which has been held by Neumann, Wiedemann, and others.

In order to prove that the axial rod, as a moving part of the apparatus, exercises no influence whatever, and that in the radial arms there is no electromotive force acting from the centre outwards, the rod was detached from the boss, and to the latter a small cup containing mercury was screwed. The upper end of the rod was then held in a fixed position by means of a suitable stand placed above the apparatus. The movable portion of the circuit consisted now only of the ring, the arms, and the boss with its mercury cup. The trials with this modified arrangement demonstrated that the direction of the current and its strength were nearly the same as when the rod was attached to the central boss and turned with it, thereby giving additional confirmation of the correctness of the Author's theory. Further experiments, in which statical electricity was employed in connection with the revolving magnet and an Edelmann's electrometer as measuring-instrument, are described in the Paper, which also contains tables of the results.

The practical outcome of the Author's work is, that the effort to increase the strength of unipolar machines by making the rotating and conducting masses larger is probably useless. The current of such machines, the points of contact of the fixed conductor with the revolving magnet being alike in all, can only be increased by strengthening the magnetism and driving them at a higher speed.

J. J. W.

On the Emission of Particles from Incandescent Metals.

By Alfred Berliner.

(Annalen der Physik und Chemie, 1888, p. 289.)

The metal, in the form of thin sheet, to be experimented on, was placed in the central portion of a long vacuum-tube, and connected to two wires sealed at each end into the glass; inside

this tube were introduced a number of short glass cylinders, which could be slid one at a time over the metal, which was raised to incandescence by the application of the necessary electric current; the deposition of the metallic particles given off could then be collected at any stage of the process on the separate cylinders and subsequently examined. The deposition of these particles depended absolutely on the existence of occluded gas, varying in direct proportion to the amount of such gas; it is, therefore, a dubious question whether the blackening of the bulbs of incandescent lamps may not be independent of any electrical action, but due wholly to the above-described effect, especially if it be remembered that carbon can absorb one thousand six hundred times its volume of gas; and thus that the traces of gas remaining after exhaustion of the bulbs would be occluded at each time of cooling, and again emitted when re-heated, carrying with it some particles of carbon as the result of volcanic eruptions on a microscopic scale.

F. J.

On the Distribution of Energy in the Spectra of Solids.

By Vladimir Michelson.

(Journal de Physique, 1887, p. 467.)

From a theoretical treatment of the subject, the Author deduces the law that the length of wave corresponding to the maximum energy is inversely proportional to the square root of the absolute temperature of the source. Mr. Langley's experimental observations appear to confirm this theory. Another law he deduces is that the total radiant energy emitted by a solid is in constant relation to the product of the maximum energy of the normal spectrum by the length of the corresponding wave, or otherwise that the area of each curve of energy is in the direct ratio of the area of the rectangle having for its sides the co-ordinates of the summit of this curve. This law is also verified to a certain extent by Mr. Langley's experiments.

Assuming with Mr. Stefan that the radiant energy emitted by a body is in the direct ratio of the fourth power of the absolute temperature, the Author finds his theoretical curves of energy agree with Mr. Langley's experimental ones. Thus the radiant energy represented by the ordinates, diminishing as it does in both directions, extends indefinitely in the direction of the less refrangible rays. When the temperature augments, all the ordinates increase; those which represent the energy of the more refrangible rays increasing more rapidly than those which correspond to the longer undulations. The theoretical curves of the normal spectrum, as well as Mr. Langley's prismatic curves, are not symmetrical; the greater portion of their area is situated to the right of the maximum ordinate, or in the direction of the more

refrangible rays. In the same way the fall of each curve is more rapid in the direction of the shorter waves.

The difference between theory and observation is accounted for to a certain extent by the circumstances that the theoretical formulas are but a first approximation, that these formulas have been deduced for solids, and not for such bodies as the sun; and, also, that in our atmosphere, as well as in the colder regions of the gases surrounding the sun, the phenomenon of a fall of solar energy takes place.

E. F. B.

Illumination of Plane Surfaces. By C. E. GUILLAUME.

(La Lumière Électrique, vol. xxvi., 1887, p. 101.)

In arranging for the illumination of large plane surfaces, such as railway platforms or the floors of factory sheds, it may be required to dispose of a given number of lamps, of given illuminating powers, so as either to produce the greatest possible uniformity of illumination throughout, or the maximum intensity at given points.

The intensity at a point A, due to a single lamp P vertically above a point N of the surface, is given by

$$i = k\,y\,(x^2 + y^2)^{-\frac{3}{2}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where AN = x, PN = y, and k is a constant depending only on the power of the lamp and the units employed. If x be given, the illuminating effect at A is a maximum when the lamp is at such a height that PAN = 35° 16′. For two lamps of equal power, at the same vertical height, the middle point O of the line NN′, joining the feet of the verticals through the two lamps, is a point of maximum or minimum illumination, according as the height of the lamps is greater or less than the distance between them; or, according as PON and P′ON′ are greater or less than 63° 26′. The most effective, though not by any means the most uniform, distribution is obtained by making these angles equal to 35° 16′.

Making i constant in (1), a curve may be described, passing through the origin A, and symmetrical about the vertical axis Ay. If this curve be made to revolve about Ay, it describes a surface touching the illuminated plane at A, and such that a lamp of given power, situated anywhere upon it, will have the same illuminant effect on a small element of the plane about the origin. A series of such curves, drawn to any convenient scale, will enable the effect at the origin of any given distribution of lamps to be determined graphically, by simply plotting out their positions upon the diagram. The inverse problem, of determining the distribu-

tion required to produce a given effect at a given point, is in general indeterminate; but when limited by various practical considerations, the graphical method may be applied with great advantage to its solution.

W. J. I.

Vulcanized Wood Pulp. By M. L. Deering.

(Journal of the Association of Engineering Societies, New York, Feb. 1888, p. 52.)

This Paper was read to the Civil Engineers' Club of Cleveland, and is a continuation of a Paper on wood pulp by the same writer, already noticed.[1] In prosecuting his experiments in vulcanization, his objects were three:—To obtain a material thoroughly impervious to moisture and to oil, also to alkalis and acids in a marked degree; a solid article with high tensile resistance; and a simplification of the process of manufacture.

Spruce wood, in sheets as it comes from the mill, is beaten into pulp. Pitch is treated in an electric bath, by which its nature is altered, and it is rendered fit for mixing freely and intimately with water and pulp, in the proportion 1 of pitch to 20 of pulp. The mixture is beaten in another engine containing water heavily charged with electricity, and is then formed by pressure into pails, wash-basins, &c., in roughing moulds in the usual manner. Next, it is laid in a smooth mould, of the exact shape of the article to be made, and is vulcanized in this mould at a temperature of from 325° to 350° Fahrenheit.

The product is a substance of uniform strength, colour, and density, averaging 9,000 lbs., or about 4 tons, of tensile strength per square inch. It is capable of taking a high polish, resembling that of gutta-percha or india-rubber. It can be filed, drilled, or tapped, like a piece of iron. It is a good insulator. It will not melt or burn; it may ignite and carbonize while in contact with the fire, but when it is withdrawn from the fire, carbonization ceases.

D. K. C.

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[1] Minutes of Proceedings Inst. C.E. vol. lxxxviii. p. 562.

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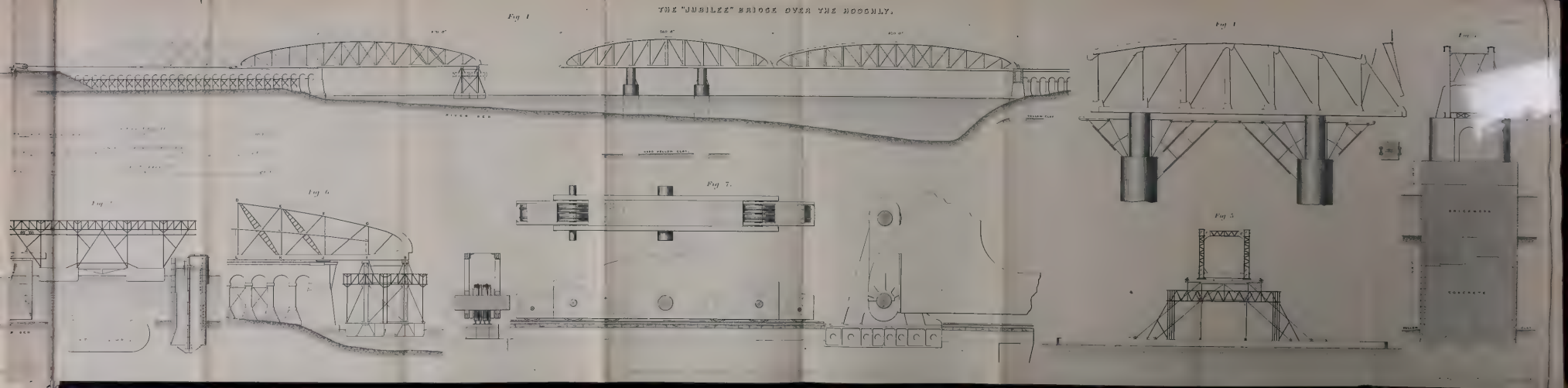

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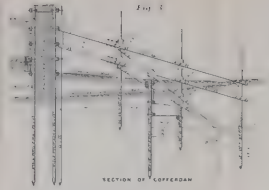
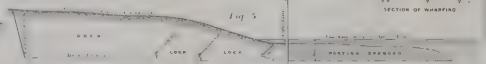
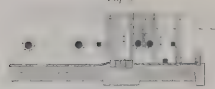


SECTION OF COFFERDAM

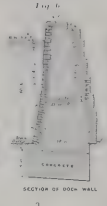
SECTION OF RIVER EMBANKMENT



SECTION OF DOCK ON LINE M M

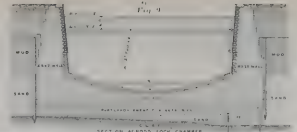


INNER END OF LOCK, SHOWING SLUICES

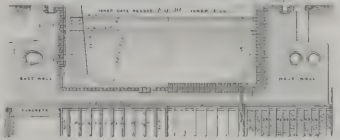


SECTION OF DOCK WALL

SECTION OF WHARFING



SECT ON ALBERT'S LOCK CHAMBER

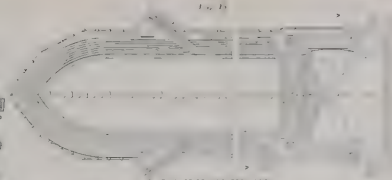


SECTION ACROSS LOCK

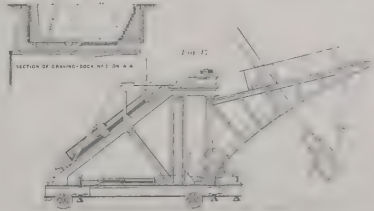
PLAN OF OUTER SILL

SECTION ON A A SECTION ON B B PLAN

OUTER LOCK GATES.



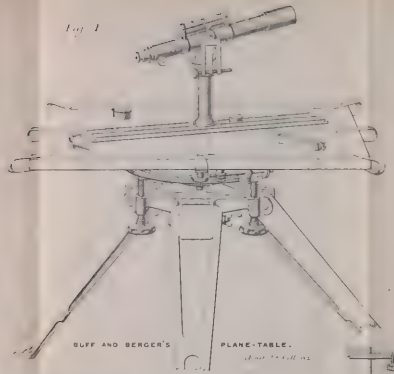
PLAN OF GRAVING-DOCK N°2



SECTION OF GRAVING-DOCK N°2 ON A A

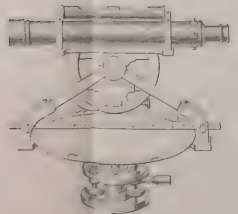
HYDRAULIC ELEVATOR

Fig 1



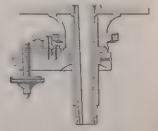
BUFF AND BERGER'S PLANE-TABLE.

Fig 2



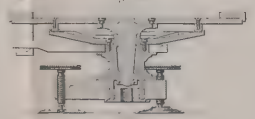
EDGEWORTH TACHEOMETER.

Fig 3



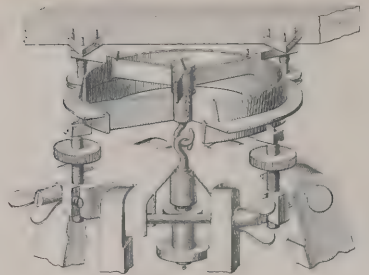
PRUSSIAN PLANE-TABLE MOVEMENT.

Fig 4.



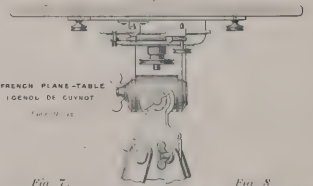
HEYDE'S PLANE-TABLE.

Fig 5



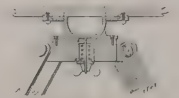
U.S. COAST SURVEY PLANE-TABLE.

Fig 6.



FRENCH PLANE-TABLE (GENOU DE GUYNOT)

Fig 7.

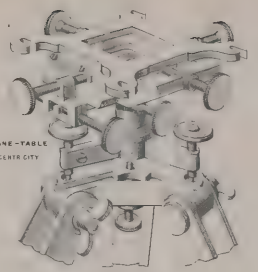


GURLEY'S PLANE-TABLE.

Fig 8

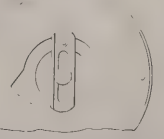
JOHNSON'S PLANE-TABLE.

Fig 9.

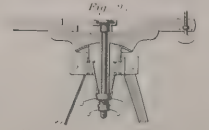


BAUERNFEIND PLANE-TABLE
ADJUSTMENT FOR ECCENTRICITY

Fig 10

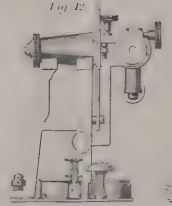


FRENCH MILITARY PLANE-TABLE (CALOTTE SPHERIQUE)



DO DO ADJUSTMENT FOR ECCENTRICITY.

Fig 12

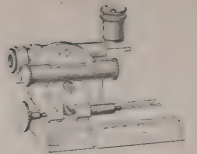


PRUSSIAN KIPPREGLE.
1875 PATTERN.

Fig 13

GERMAN KIPPREGLE.
OLD PATTERN.

Fig 14



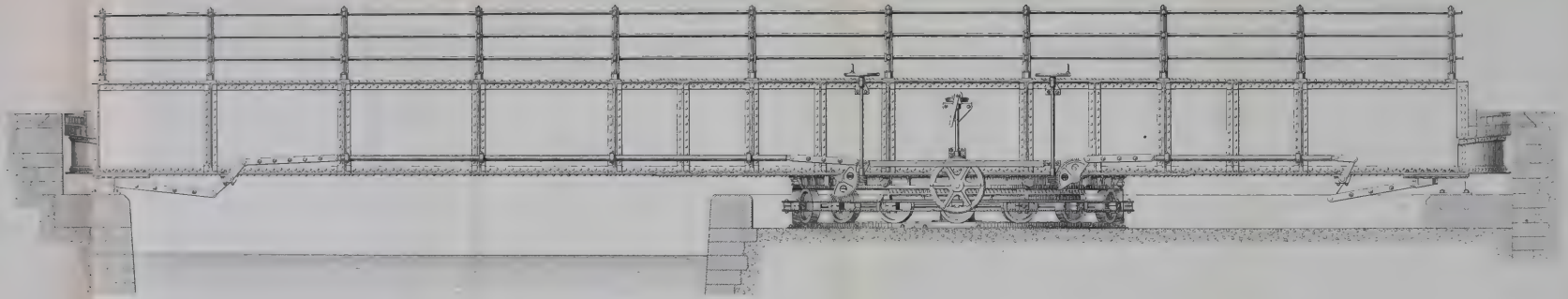
FRENCH MILITARY ALIDADE.

Fig 15.

NILGARD ALIDADE.

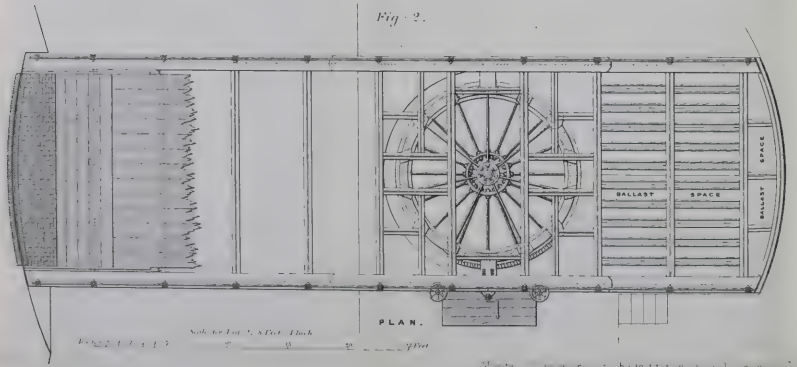
CASTLE-TOWN SWING BRIDGE.

Fig: 1.



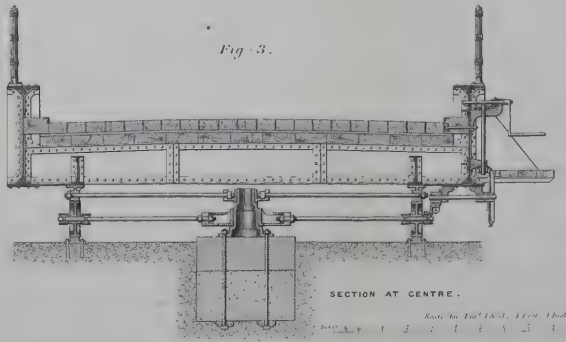
ELEVATION.

Fig: 2.



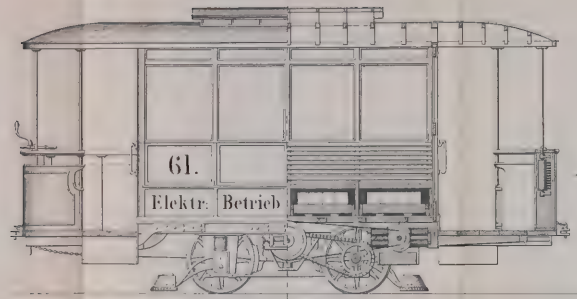
PLAN.

Fig: 3.



SECTION AT CENTRE.

Fig 1.



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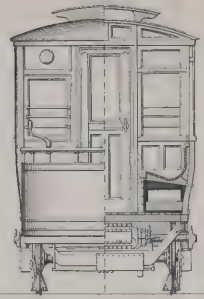


Fig 4.

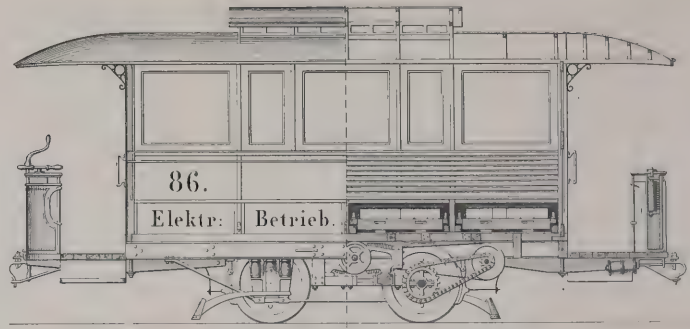


Fig 6

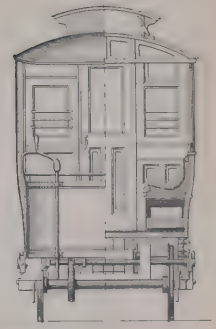


Fig 2.

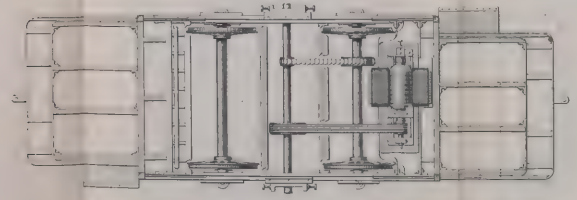


Fig 5.

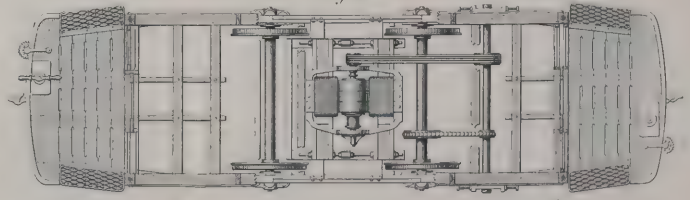


Fig. 1

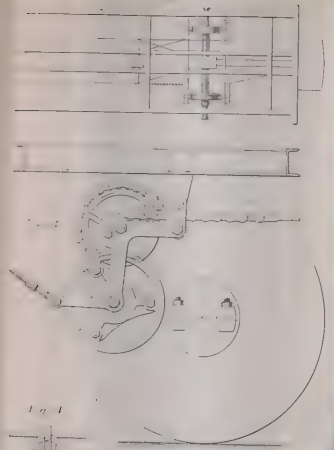


Fig. 2

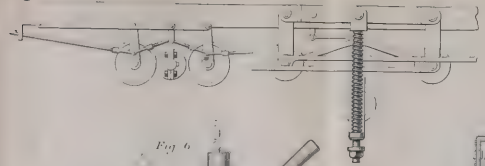


Fig. 3

Fig. 4

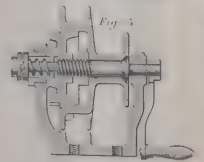


Fig. 5

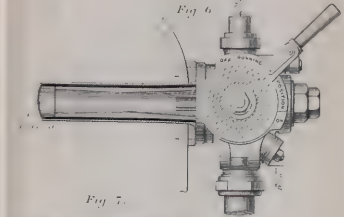


Fig. 6

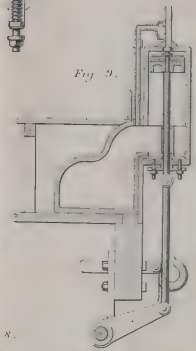
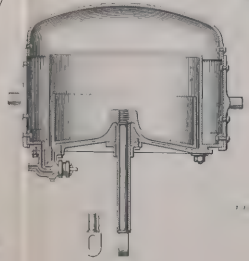


Fig. 7.



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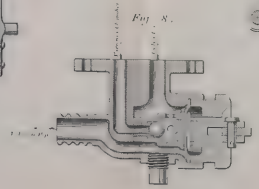


Fig. 9.

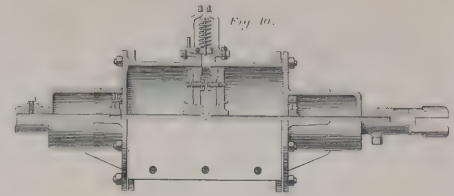


Fig. 10.

Fig. 11.

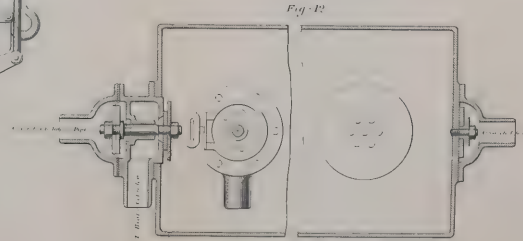
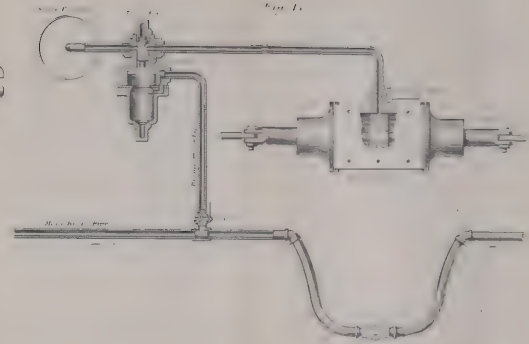


Fig. 12



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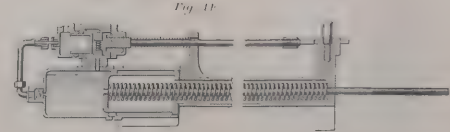


Fig. 14

Fig. 1

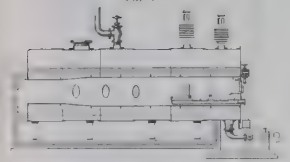


Fig. 2

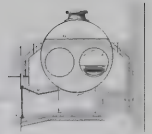


Fig. 3

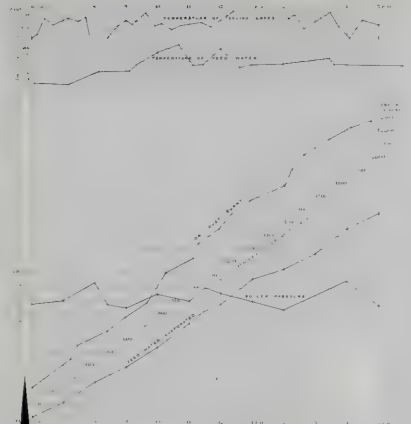


Fig. 4

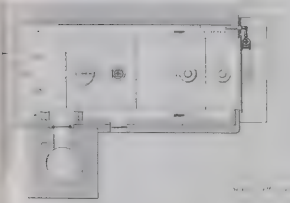
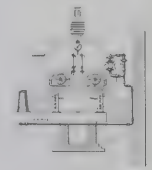


Fig. 5



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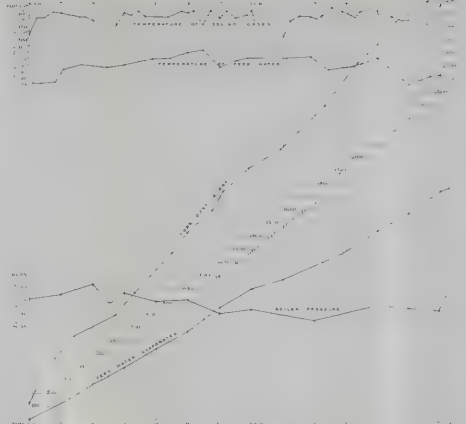
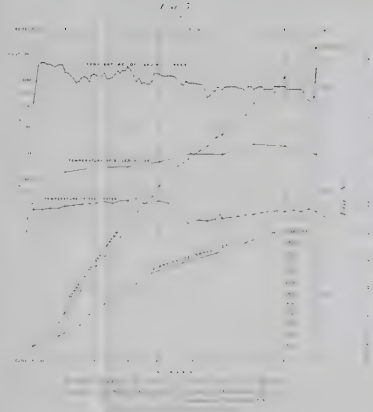


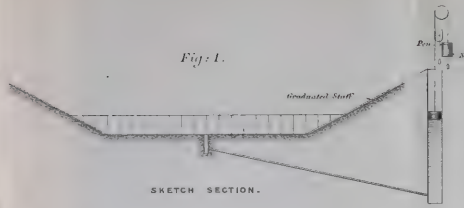
Fig. 7



RECORDS OF HORIZONTAL BOILER TESTS

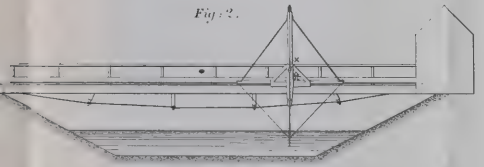
RIVER GAUGING AT THE VYRNWY RESERVOIR.

Fig: 1.



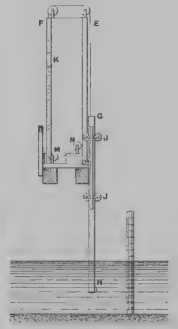
SKETCH SECTION.

Fig: 2.



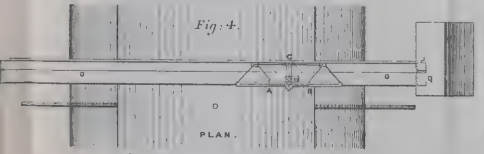
ELEVATION.

Fig: 3.



SECTION.

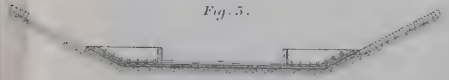
Fig: 4.



PLAN.

CURRENT METER BRIDGE

Fig: 5.



ELEVATION OF NOTCH GAUGE

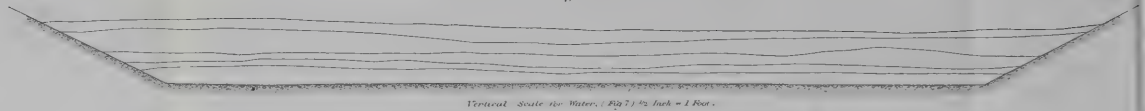
Fig: 6.

SECTION OF NOTCH.

Scale for River Sections 1 Inch = 1 Foot

Scale for Fig: 6 1 Inch = 1 Foot

Fig: 7.



Vertical Scale for Water. (Fig 7) ½ Inch = 1 Foot.

Fig: 8.

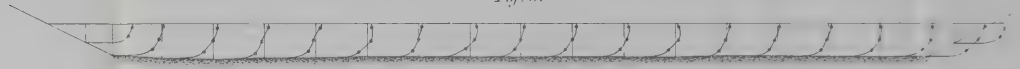


Fig: 9.

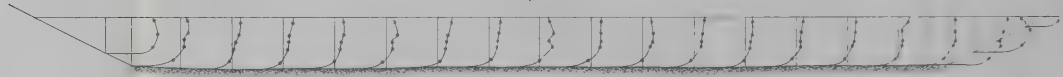


Fig: 10.

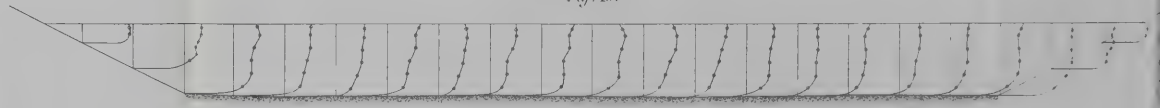
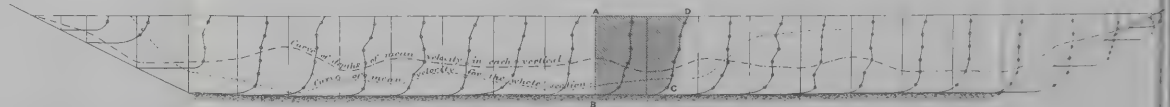


Fig: 11.



the Velocity Curves overlaps. A B C D = the Velocity Curve for the Station A B.

Horizontal Scale for Velocity Diagrams, and Scale for Fig: 1 & 3 ½ Inch = 1 Foot.

Scale for Fig: 6 ½ Inch = 1 Foot

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